ABSTRACT

Title of Dissertation: ESSAYS ON WHOLESALE BANKING AND THE MACRO-ECONOMY

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This dissertation studies how the wholesale banking sector impacts the real economy. As the wholesale banking sector is more sensitive to market conditions compared to the traditional retail banking sector, I investigate how changes in asset return uncertainty can induce fluctuations in real activities through the two sectors in different manners.

In the first chapter, I first document empirically the evolution of bank assets and leverage ratios separately for the wholesale banking sector and the retail banking sector and highlight their differences. Secondly, I propose a theoretical framework that distinctly models two different types of banks to explain the relative growth of wholesale banks and the difference between types of banks in the behavior of leverage. I then investigate the implications of the size of wholesale banking for the business cycle volatility of the real economy. The wholesale banking sector has grown drastically since the 1980s and is more volatile in the data compared to the retail sector. In the model, wholesale banks are more sensitive to risk shocks relative

to retail banking due to a difference in the leverage constraint, which leads to more volatile aggregate capital, investment, and output when the wholesale banking sector is more sizable.

The second chapter explores empirically the role of financial intermediaries in the link between macroeocnomic uncertainty and aggregate economic outcomes, with a focus on bank leverage ratios. In VAR models including bank balance sheet variables for both retail and wholesale banking sectors, increased levels of aggregate uncertainty significantly reduce bank leverage ratios and bank assets, and subsequently reduce aggregate investment and production. Compared to traditional retail banking sector, wholesale banking sector is especially sensitive to changes in macro-uncertainty and therefore plays a more important role in this channel.

ESSAYS ON WHOLESALE BANKING AND THE MACRO-ECONOMY

by

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Chapter 1: The Evolution of the Wholesale Banking Sector and the Macro-Economy

1.1 Introduction

The 2007-2008 financial crisis has brought financial frictions back into the focus of macroeconomic literature. In particular, a wave of recent macroeconomic models have introduced financial intermediaries to study their impact on the real economy. However, one area this literature has yet to address adequately is the distinctive role of the wholesale banking sector.

Wholesale banks refer to those that are based on capital market financing rather than traditional intermediation between depositors and ultimate borrowers. Compared to traditional retail banks, they tend to be highly leveraged, often with short term debt such as commercial paper or repurchase agreements, and tend to borrow heavily from other financial institutions in the interbank market (wholesale market) as opposed to the traditional retail market for household deposits. Some recent studies have noted the increasing importance of wholesale banking. Adrian and Shin (2010b) [5] provide evidence that market-based banking has grown drastically since the early 1980s and has overtaken traditional banking, and note the important distinction between market-based banks and traditional commercial banks. Given their reliance on interbank borrowing, market-based intermediaries are much more sensitive to capital market conditions. Gertler, Kiyotaki, and Prestipino (2016) [34] emphasize that the epicenter of the recent financial crisis lay in the malfunctioning of the wholesale banking sector, with dry-ups and bank runs, while the retail markets remained relatively stable.

The growth of wholesale banking reflected a range of financial innovations taking place in recent decades, most importantly the securitization process. Securitization refers to the pooling of mortgages, loans, receivables, and other financial cash flows into securities that are then tranched according to credit and liquidity characteristics. When banks sell their loans into the securitization market, they distribute the risks associated with these loans across a wider range of end investors. This improved risk-sharing element represents an economic efficiency. In addition, catering to the demand for safe assets, various kinds of insurance (for example credit default swaps) make securitized loans appear safe, creating safe ("AAA" rated) long-term assets. By doing so, debt instruments beyond the low-risk ("senior") tranches of loans can be repackaged into safe, short-term, and liquid claims held by investors. This further enhances the liquidity of asset markets. Moreover, the pooling and tranching process can make the senior tranches of loans relatively easy to evaluate, even for nonspecialized investors that do not have sufficient skills to judge credit quality. The securitization process thus diversifies idiosyncratic risks, improves the (perceived) safety of loans, and reduces monitoring complexity for investors. It is primarily the wholesale sector, as opposed to the retail sector, that engages in this securitization process, since the sophistication of these securities require the creditors be highly informed to evaluate payoffs and have a close working relationship with the debtors. Therefore, the funding of credit through the shadow banking system significantly reduced the cost of borrowing and potentially increased the efficiency of credit intermediation for the wholesale banking sector.

Another factor that may have contributed to the growth of the wholesale banking sector is a lessened degree of banking regulation pertaining to the interbank market. One example is the repeal of the the 1933 Glass-Steagall Act. After the 1929 stock market crash, Congress passed the Glass-Steagall Act, which separated wholesale and retail banking activities. Traditional retail banks were offered deposit insurance but were no longer allowed to underwrite or deal in securities, while banks that underwrote and dealt in securities were no longer allowed to have close connections to commercial banks, such as overlapping directorships or common ownership. Starting in the 1980s, the banking industry experienced a period of continual reinterpretation and liberalization of the Glass-Steagall Act until it was eventually repealed in 1999. In the 1980's, the Federal Reserve Bank reinterpreted sections of the Glass-Steagall Act to allow traditional banks to earn up to 5% of their revenue from securities transactions. By the end of the 1980's, the limit was raised to 10% of revenues. Additionally, banks were permitted to do a small amount of underwriting. In 1996, the limit was increased again. Traditional retail banks were now allowed to earn up to 25% of their revenues from securities transactions. The Gramm-Leach-Bliley Act of 1999 finally repealed two sections of the Glass-Steagall Act, allowing retail banks to be affiliated with wholesale bank entities, and allowing interlocking management and employee relationships between banks and securities firms. This process may have facilitated the expansion of the interbank market, as it gradually made it easier for retail banks to provide credit to wholesale banks. In addition to this process of deregulation, the growth of the wholesale banking sector may also have been related to an increasing degree of regulatory arbitrage, in which banks found new ways to circumvent regulations in pursuit of bigger profits. In fact, Gertler, Kiyotaki, and Prestipino (2016) [34] comment that regulatory arbitrage and financial innovation are two factors behind the rise of wholesale banking.

Key among the many differences between the two types of banking is the behavior of bank leverage. Bank leverage refers to the ratio of total assets (lending) to equity (net worth). Higher leverage allows banks to lend more for a given level of net worth. Fluctuations of bank leverage lead to fluctuations in bank lending activity and thus have direct implications for the supply of bank credit, which in turn can affect aggregate investment and real economic activity. The importance of fluctuations in bank leverage has recently entered the spotlight as a result of the financial crisis. A particularly influential strand of literature has focused on the role played by the deleveraging of the financial intermediation sector in the unraveling of the crisis (e.g. Brunnermeier (2009) [23], Gorton and Metrick (2010, 2012) [36, 37]).

Bank leverage also exhibits cyclical behavior outside of crisis periods (Adrian and Shin (2010a, 2011) [4, 7]). Importantly, there is empirical evidence suggesting marked differences in the cyclical behavior of leverage between the two types of banks, for instance in Adrian and Shin (2010a) [4] and in Nuño and Thomas (2017) [44]. Specifically, Nuño and Thomas (2017) [44] focus on the time period since the early 1980s, when wholesale banks experienced marked growth. Both volatility of bank leverage and pro-cyclicality of leverage (in terms of the correlation between leverage and total assets) are significantly higher for broker-dealers and finance companies than for depository banks. Additionally, there is a higher correlation between bank leverage and GDP for broker-dealers and finance companies.

Due to the drastic differences in their financing structure as well as behavior of key variables, the increasing presence of wholesale banks relative to retail banks may have important implications for the functioning of the financial system and aggregate volatility. Thus, it is increasingly clear that modeling the differences between these two types of banks is necessary to properly judge the effect of the changing nature of the financial intermediation sector.

This study proposes a theoretical framework that explains the differing behavior of these two types of banks. The model achieves two goals. First, I explain the recent growth of the wholesale banking sector as well as the difference in bank leverage volatility between the two types of banks. Second, I study the implications of the growth of wholesale banking for the volatility of aggregate investment and output. I limit my study to the period from the 1980s up until the eve of the financial crisis, focusing on the build-up of vulnerabilities in the financial system prior to the actual financial crisis.

Specifically, I study a DSGE model with six types of agents: households, capital producers, institutional investors, retail banks, wholesale banks, and firms. Households, capital producers, and institutional investors are representative and operate nation-wide, whereas firms, retail banks and wholesale banks are segmented on a continuum of islands. On each island there is one representative wholesale bank, one representative retail bank, and many competitive firms of two types. Firms produce final output with capital and labor. They take out loans from both types of banks to purchase capital and are subject to island-specific shocks to effective capital.

The firms are of either a high or low ("substandard") type, in the sense that the distribution of idiosyncratic shocks is different between the two types, where the substandard type is more exposed to risks. The banks lending to firms will default if their earnings are not sufficient to pay back their own debt, in which case their lenders take their remaining assets. Due to the limited liability nature of the debt contract, banks have an incentive to invest in substandard firms to enjoy the benefit of upside risk in their assets while leaving their creditors to bear the consequences of downside risk. This constitutes a risk-shifting moral hazard problem, as described in Adrian and Shin (2013) [10], on the part of banks. To prevent this risk-shifting, creditors limit their lending to banks, resulting in a leverage constraint. This reflects a friction between banks and their investors. There is no friction between banks and firms.

Both types of banks lend to firms, but there is a cost of managing loans to firms that differs between the two types of banks. Wholesale banks also pay an extra financing cost for engaging in the interbank market. In addition, when investing in firms, the leverage constraint imposed on the wholesale bank when investing in firms is more strict than that of the retail bank. This reflects the fact that investors in the interbank market are more skilled at monitoring than household depositors in the deposit market. All lending and borrowing on both the interbank market and the deposit market happen via a representative, nation-wide institutional investor. The institutional investor collects funds from the ultimate creditors (households), lends to banks on both markets, and manages and monitors these loans.

I calibrate the model to the U.S. economy and identify an "earlier" and a "later" stage when the wholesale sector was less and more important, respectively. The first result of the model is that the steady state share of the wholesale banks (in terms of assets) depends on their relative cost of managing bank assets as well as financing cost on the interbank market. In my quantitative exercise, I assume that the parameters governing the relative cost of asset management have decreased over time for the wholesale banking sector, to reflect an increase in intermediation efficiency as a result of financial innovations as explained earlier. I also assume that the financing cost in the interbank market has decreased over time, reflecting the process of deregulation and increasing degrees of regulatory arbitrage. Changes in these parameters can explain the recent trend growth of wholesale banking.

Next I compare the volatility of aggregate bank leverage, investment, and output in response to shocks to the cross-sectional volatility of asset returns for the two parameterizations of the economy ("earlier" and "later"), the latter with a more prominent role for wholesale banks. The shocks to volatility considered here are shocks to the cross-sectional standard deviation of capital returns, or "risk shocks" as featured in papers like Christiano, Motto, and Rostagno (2014) [27]. These shocks are of increasing relevance as they can be interpreted as exogenous changes in uncertainty, and such shocks are widely considered to have been important in the recent crisis. Moreover, a recent thread of literature has highlighted the link between volatility of asset returns and borrower leverage. For example, Geanakoplos (2010) [31] and Fostel and Geanakoplos (2008) [30] investigate the asset price implications of shocks that reduce the volatility of expected asset returns, which due to lenders' insurance against increased uncertainty lead to tighter margins (the inverse of the leverage ratio, or the down-payments of debt). Brunnermeier and Pedersen (2009) [24] consider similar mechanisms. Recent studies along the lines of Bloom (2009) [20] also suggest that exogenous changes in volatility are an important driving force behind business cycle fluctuations. In addition to these risk shocks, I also examine the model's responses to traditional TFP shocks.

Under some assumptions, an increase in cross-sectional volatility leads to an increased incentive for banks to lend inefficiently to substandard firms, which in turn results in a tighter leverage constraint imposed by their lenders. As such, increased volatility leads to reduced bank leverage. The decline in bank assets subsequently results in reduced lending and therefore a contraction in capital investment and output. This is the mechanism featured in Nuño and Thomas (2017) [44], which they call "the volatility-leverage channel".

Importantly, due to better monitoring skills as well as a higher sensitivity to market conditions of interbank lenders relative to depositors, the leverage constraint is implemented more strictly for wholesale banks than for retail banks. As a result, the volatility-leverage mechanism affects wholesale banks more than retail banks, so that the volatility of wholesale bank leverage is higher than that for retail banks, as observed in the data. Combined with the drastic growth of the wholesale banking sector, exogenous changes in asset return risk lead to more volatility of overall bank leverage, investment, and output in the "later" stage when wholesale banking is more significant compared to the "earlier" stage when wholesale banking is far less important than traditional retail banking.

The study contributes to the recent literature incorporating frictional financial intermediaries into standard frameworks. This literature features important recent contributions by Christiano, Motto and Rostagno (2010) [26], Curdia and Woodford (2010) [28], Gertler and Karadi (2011) [32], and Gertler and Kiyotaki (2010) [33] among others. However, this literature mostly ignores the important distinction between wholesale and retail banking, as is pointed out in Gertler, Kiyotaki, and Prestipino (2016) [34], who develop a model of banking crises that is extended to feature wholesale banking in addition to retail banking. Their focus is on explaining the recent financial crisis, and they do not focus on the cyclical behavior of bank leverage. In addition, their model adopts a funds-diversion moral hazard problem on the part of the banks and does not have a role for shocks to the cross-sectional risk of asset returns of the economy, which have been prominently featured in debates about the causes of the recent crisis.

Relative to Gertler, Kiyotaki, and Prestipino (2016) [34], I present a model that features a risk-shifting moral hazard problem and that links volatility of asset returns to the cyclical behavior of bank leverage. Based on the difference in the severity of the moral hazard friction between wholesale and retail banks, the model explains the difference in the behavior of bank leverage between the two types of banks and the implications of the growth of wholesale banking for aggregate volatility.

Another recent strand of literature provides both evidence and theory on the cyclicality of bank leverage, with contributions from Brunnermeier and Pedersen (2009) [24], Geanakoplos (2010) [31], Ashcraft, Garleanu and Pedersen (2011) [11], Gorton and Ordonez (2014) [38], and Adrian and Shin (2013) [10]. This literature points to a link between changes in uncertainty/risk and the observed behavior of leverage, yet these results thus far have not been incorporated into a dynamic quantitative framework, and especially not a framework incorporating different types of financial intermediaries.

Thus this study contributes to the literature by proposing a DSGE framework incorporating two different banking sectors, featuring an important link between the risk of asset returns and the business cycle volatility of the real economy through financial intermediation and in particular the behavior of bank leverage.

The rest of the paper is organized as follows. Section 1.2 presents empirical findings on bank assets and leverage since 1980 for different banking sectors. Section 1.3 presents the model details. Section 1.4 explains the mechanism of the model. Section 1.5 and 1.6 present quantitative exercises and the results of the model. Section 1.7 concludes.

1.2 The Evolution of Wholesale and Retail Banking Sectors

1.2.1 Data and Methods

This section documents empirical findings on the wholesale and retail banking sectors in the United States since 1980, with a focus on the behavior of bank assets and leverage. Data are quarterly series from the U.S. Flow of Funds. In this section I include data from the early 1980s to 2019 to present the evolution of the two banking sectors, although in my model I limit my focus to the build up to the crisis, from the early 1980s to the eve of the crisis in 2007.

Financial intermediaries are categorized into retail or wholesale sectors based on their main source of funding/liabilities. Instruments that are supplied by financial intermediaries and demanded by households are considered retail funding, while instruments that are mainly traded among financial intermediaries are considered wholesale funding. Table 1.1 lists the specific instruments falling into each category. This categorization roughly follows that used in Gertler, Kiyotaki, and Prestipino (2016) [34].

Retail Funding	Checkable deposits and currency Time and saving deposits Money market mutual fund shares Mutual fund shares
Wholesale Funding	Security repurchase agreements Financial open market paper Agency/GSE backed securities Financial corporate bonds Retail loans to wholesale

Table 1.1: Classification of Funding Instruments

Based on this classification, intermediaries are categorized into retail or wholesale banking as follows:

Retail Banking Sector	Private Depository Institutions	63.41%
	Mutual Funds	23.86%
	Money Market Mutual Funds	12.73%
Wholesale Banking Sector	Security Broker-Dealers	21.11%
	ABS Issuers	20.60%
	GSE Mortgage Pools	19.09%
	Government Sponsored Enterprises	13.34%
	Finance Companies	9.64%
	Holding Companies	8.12%
	Funding Corporations	6.45%
	Real Estate Investment Trusts	1.64%

Table 1.2: Categorization of Banking Sectors

Data on total assets are available for all of the subsectors listed above from the Flow of Funds. The last column of Table 1.2 shows the percent distribution of total assets within retail and wholesale sectors for the first quarter of 2007, on the eve of the financial crisis. For the calculation of leverage ratios, I divide total assets by equity capital. Data on equity capital are available during the period analyzed for only five sub-sectors: U.S. charted depository institutions, security broker-dealers, finance companies, government sponsored enterprises, and holding companies. U.S. charted depository institutions is the main sector within private depository institutions: its assets are about 84 % of all assets of private depository institutions at the beginning of 2007. Security broker-dealers, finance companies, government sponsored enterprises and holding companies together make up more than half of the total assets of the wholesale banking sector in the first quarter of 2007.

All data series are deflated by the GDP Implicit Price Deflator (obtained from the Bureau of Economic Analysis). Data are also adjusted for discontinuities in the Flow of Funds data construction.[1]

1.2.2 Bank Assets

As noted earlier, the wholesale banking sector has experienced significant growth in the past three decades. Figure 1.1 and Figure 1.2 document the growth of wholesale banking relative to retail banking from 1980 to 2019. Figure 1.1 displays the log of total financial assets (in millions of USD in 2012) for both the wholesale and retail banking sectors, and Figure 1.2 plots the share of wholesale banks in the total assets of the wholesale and retail banking sectors combined. In the early 1980s, the wholesale bank sector held roughly 25% of total bank assets. By 2007, the share of wholesale bank assets had risen to over 50%, on par with the assets held by retail banks.

[1]Data on levels (series identifier 'FL') from the Flow of Funds suffer from discontinuities that are caused by changes in the definition of the series. The Flow of Funds constructs discontinuities series (series identifier 'FD') to correct for such changes. Specifically, each series of the flow data (series identifier 'FU') is equal to the change in level outstanding less any discontinuity: $FU_t = FL_t - FL_{t-1} - FD_t$. Therefore, the flow data are free from such discontinuities. In order to adjust for discontinuities in the level series, the value of the level in the first period of the sample is used and the flows data are accumulated onwards to obtain level data for subsequent periods.

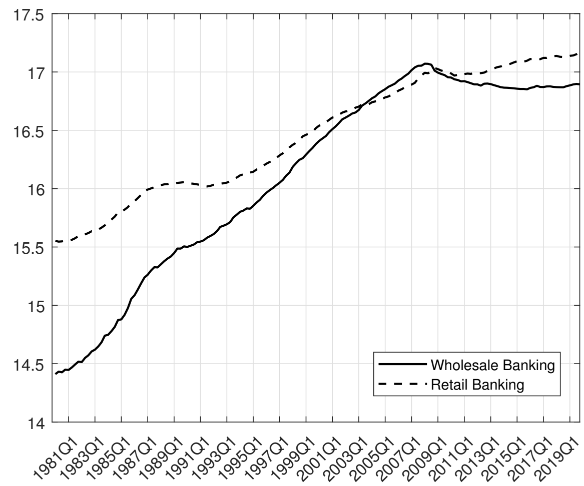

Figure 1.1: Wholesale and Retail Bank Assets

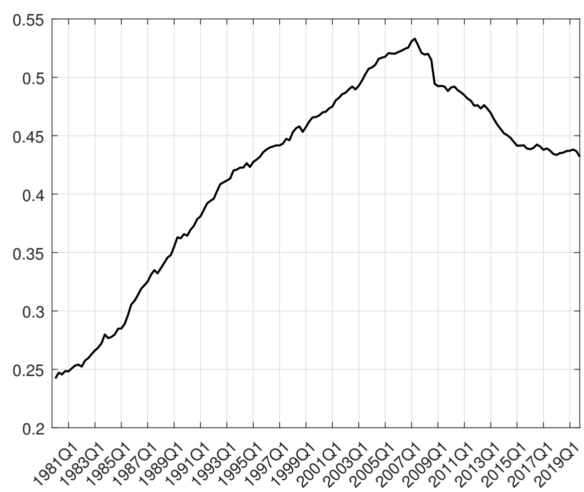

Figure 1.2: Share of Wholesale Bank Assets

The asset levels plotted here are total financial assets from the Flow of Funds data, obtained by summing over all sub-sectors within both the retail and wholesale sectors. It is worth noting that asset items for one sub-sector may be the liabilities of another sub-sector, especially within the wholesale banking sector. However, data does not exist for tracking the identity of the borrower/lender of each asset/liability item for the sub-sectors. I therefore approximate the net financial assets for each banking sector by subtracting asset items that are most likely funding instruments for other financial intermediaries.[2] Figure 1.3 shows the approximated levels of net bank assets extended to the economy along with gross levels from Figure 1.1. It can be observed that wholesale bank net assets lagged behind net retail assets in the 1980s but continued to increase to be on par with assets held by retail banks as early as the late 1990s, and were more sizable by the eve of the Great Recession. Since this is not an exact measure of netted-out assets but confirms the trend exhibited by the gross assets of the two sectors, I use gross asset measures in subsequent analyses.

Figure 1.3: Netted-out Bank Assets

The drastic growth of the wholesale banking sector may have had important implications for the overall banking system, especially if wholesale banks exhibit different behavior than the retail banking sector.

[2]Specifically, these funding items are: agency- and GSE-backed securities, security repurchase agreements, commercial paper, and equity investment in own subsidiaries.

Figure 1.4 and Figure 1.5 plot the volatilities of total financial assets for the sub-sectors listed in Table 1. U.S.- chartered depository institutions represent the "Private Depository Institutions" category (with 84% of the assets in that sector) and are the most important component of the retail banking sector. The volatility of their assets is compared to the volatility of the assets of each of the sub-sectors of wholesale banking. This comparison is split into two figures to include all sub-sectors as well as to accommodate the difference in the range of volatilities of different sectors. The volatility numbers plotted here are the standard deviations of a rolling two-year window of the underlying quarterly series, log-detrended within each four year period. Each four-year window is marked with its beginning quarter. For example, the standard deviation plotted for 2003Q1 is for the period 2003Q1 - 2004Q4.

As can be seen in Figure 1.4 and Figure 1.5, throughout the period from 1980 to 2019, the volatility of total financial assets is higher for each of the sub-sectors of wholesale banking compared to depository institutions. This fact, combined with the growth of the wholesale sector, may have significant implications for the overall volatility of the banking system. Figure 1.6 plots volatilities of total assets for retail and wholesale banking (combining all sub-sectors within each category). Wholesale banking generally exhibits higher volatility than retail banking for most of the period, and this difference is more pronounced in times of higher overall volatility.

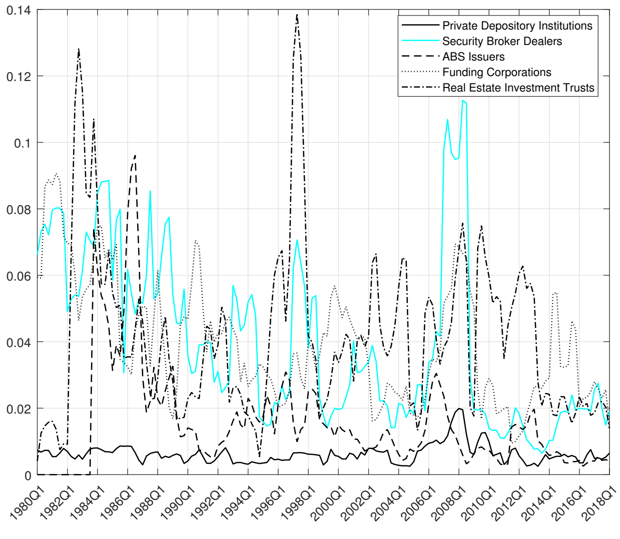

Figure 1.4: Volatility of Bank Assets - I.

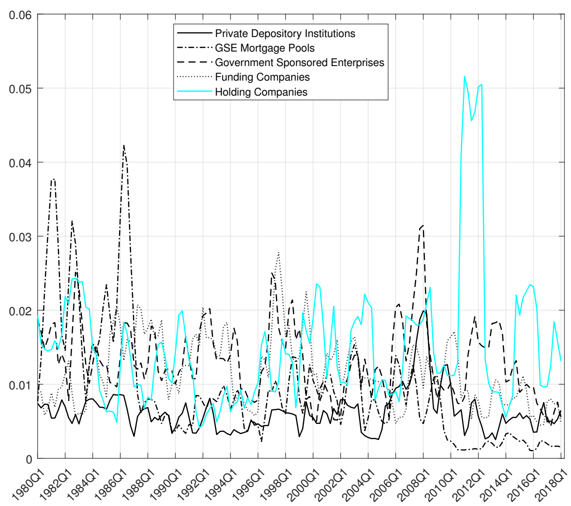

Figure 1.5: Volatility of Bank Assets - II.

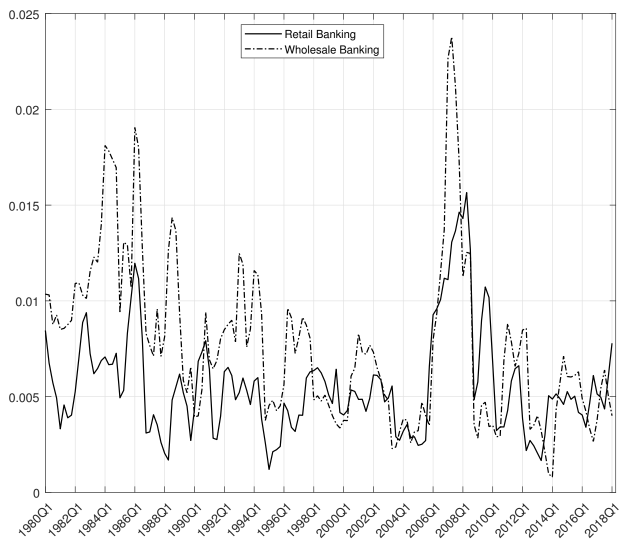

Figure 1.6: Volatility of Bank Assets - Total Assets.

1.2.3 Bank Leverage

Another significant difference between wholesale and retail banking is the behavior of bank leverage. To compute leverage, I divide total financial assets by equity capital from the Flow of Funds. Ideally I would do this for each sub-sector and approximate the overall leverage for the wholesale or retail sector by weighting the leverage of each sub-sector by its total assets. However, the equity capital series is not consistently available for all sub-sectors. Therefore in Figure 1.7 I show the leverage levels of the most significant sub-sectors of the retail and wholesale banking sectors, namely US-chartered depository institutions and security broker-dealers. I also include the total leverage of the four sub-sectors of wholesale banking with data on equity: security broker-dealers, GSEs, financial companies, and holding companies.

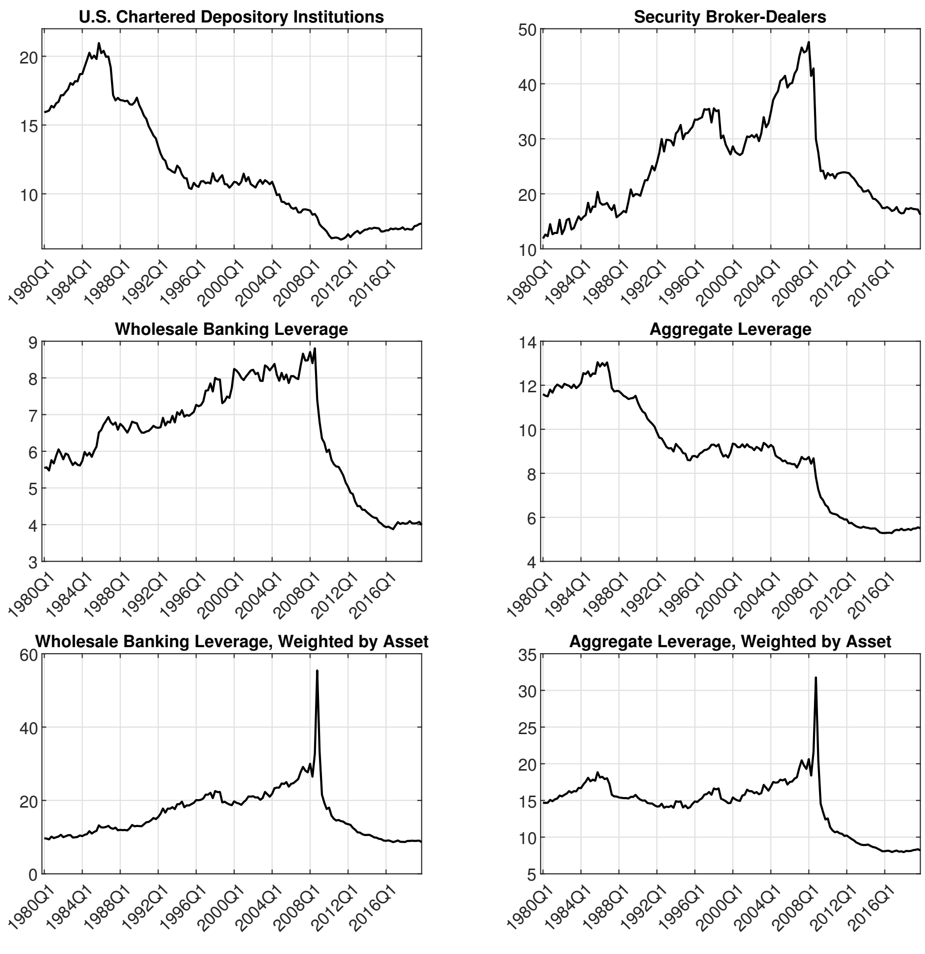

Figure 1.7: Bank Leverage Levels

Retail and wholesale bank leverage ratios exhibit different trends. For depository institutions, the leverage level dropped from about 20 in the early 1980s to about 8 before the financial crisis, while for security broker-dealers leverage grew rapidly over this period, from about 10 to over 40. I show the total leverage of wholesale banking both simply as the ratio of total assets over equity the four sub-sectors and as a weighted average of the leverage of the four measured sub-sectors (weighted by their assets on the eve of the crisis). These series show a similar trend to that of security broker-dealers, whose leverage ratio grew dramatically over time and reached its peak around the time of the crisis. Note that this figure may not fully reflect the trend of the leverage of the entire wholesale sector, as it excludes sub-sectors without equity data. However the sub-sectors included here do make up the majority of total wholesale banking sector assets. The aggregate leverage ratio is computed by summing equity and loans of U.S. chartered depository institutions and security broker-dealers. The graph of this series show a similar trend to the retail banking sector. But when weighted by assets of these two sub-sectors, aggregate leverage stayed roughly constant throughout this period, reflecting the increasing impact of a growing wholesale banking sector. Alternatively, aggregate leverage can be computed by combining all five sub-sectors, which shows very similar trends.

The volatility of bank leverage also behaves differently between retail and wholesale banking. Figure 1.8 below plots the standard deviations of log-detrended leverage for each four-year window from 1980 to 2019, again for US-chartered depository institutions and security broker-dealers, as well as the total of the four wholesale banking sub-sectors.

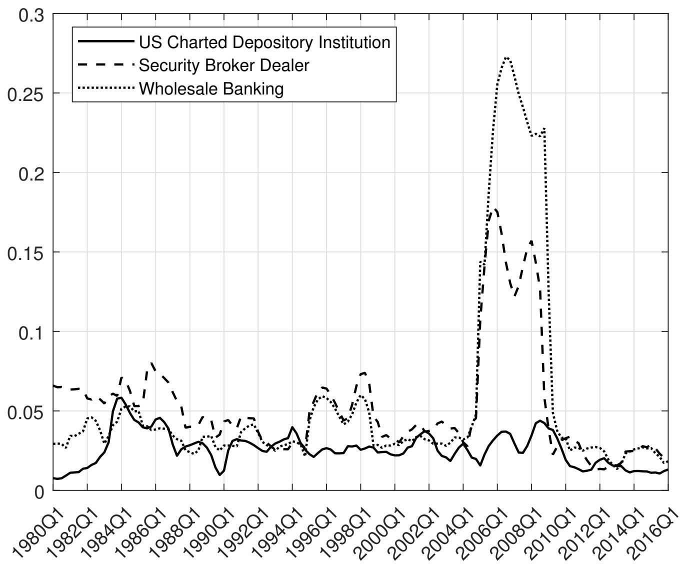

Figure 1.8: Volatilities of Bank Leverage

Throughout this period, the volatility of leverage is almost always higher for security broker-dealers than for depository institutions. The weighted average leverage for all wholesale sub-sectors also is more volatile than leverage for depository institutions for almost all of this period, following a similar trend to that of the security broker-dealers.

1.2.4 Equity and Interbank Market

Figure 1.9 below plots the levels of equity capital for U.S. chartered depository institutions, for security broker-dealers, and for all five sub-sectors combined. Along side the equity levels, Figure 1.9 also shows the ratio of equity to total bank assets (the inverse of leverage). While equity levels have grown throughout the period for both depository institutions and security broker-dealers, the ratios of equity to assets exhibit opposite trends for depository institutions and for security broker-dealers. This is in line with the declining leverage ratio for depository institutions and the increasing leverage ratio for wholesale banks. I also include the total equity for all four sub-sectors of wholesale banking, which exhibits similar trend to that of the security broker-dealers.

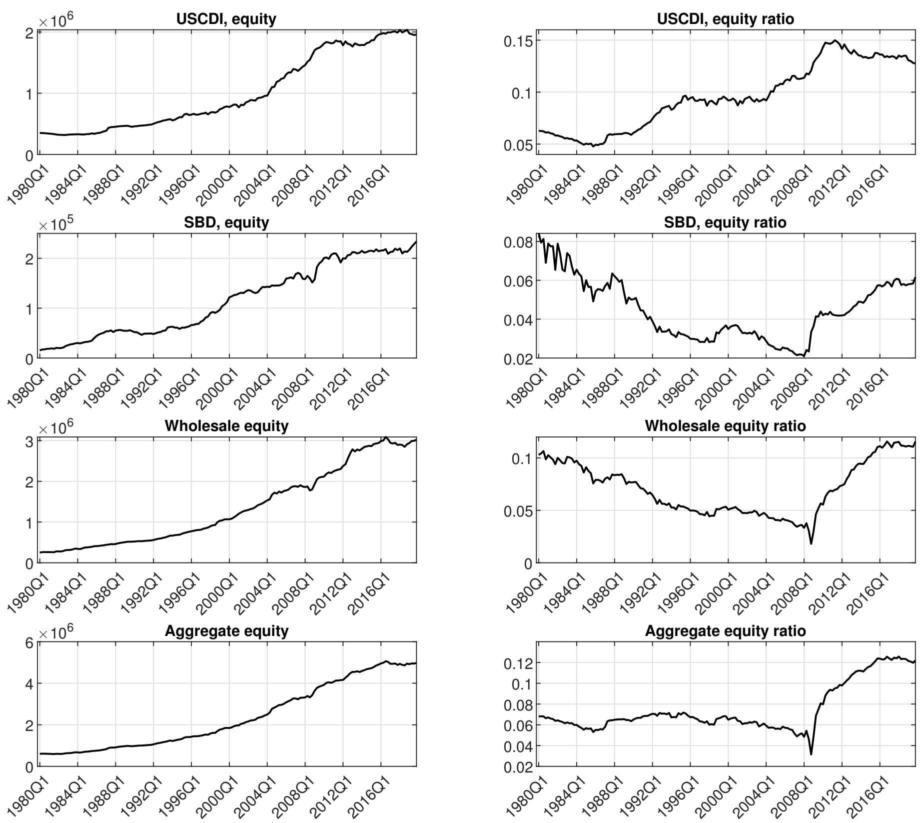

Figure 1.9: Bank Equity

Figure 1.10 also plots the evolution of aggregate interbank loans, in levels and as a percentage of the total assets of the entire retail banking sector. There is no data directly available for loans from retail banks to the interbank market. Interbank loans are therefore approximated by summing retail asset items that are most likely funding instruments of wholesale banks, namely, repurchase agreements, short-term debt securities excluding government securities, and bank loans to non-depository financial institutions. This data is obtained for all sub-sectors of the retail banking sector (private depository institutions, mutual funds, and money market mutual funds) and is added together to obtain total interbank loans. Figure 1.10 shows that interbank loans from retail banking increased from 1980 until the end of the period. Additionally, as the total assets of retail banking steadily grew from the 1980s to the 2000s, the proportion of interbank loans increased even more drastically. This reflects a growing interbank market that is associated with the expansion of the wholesale banking sector.

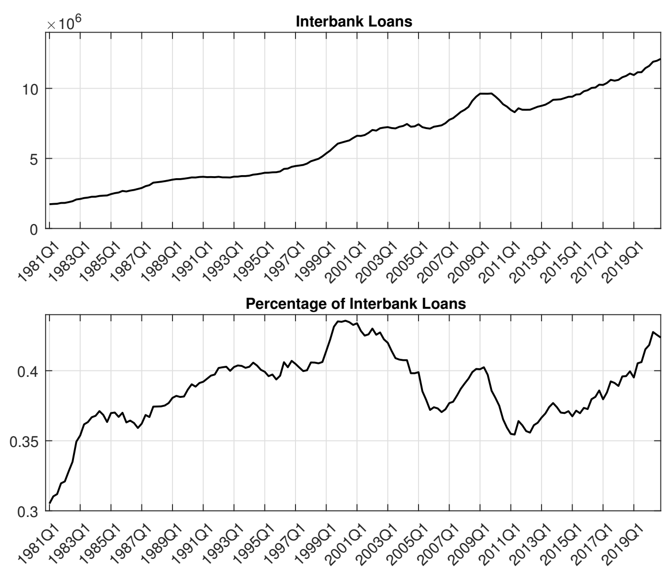

Figure 1.10: Interbank Loan, Percentage of Total Retail Bank Assets

In summary, the findings of Section 1.2 show important differences between the wholesale and the retail banking sectors. Wholesale banking is more volatile in terms of both the leverage ratio and total assets. During the period from 1980 to the eve of the Great Recession, the wholesale leverage ratio experienced a continuous and drastic increase, while retail bank leverage showed a mild decline. As the share of total assets that is intermediated through wholesale banking grew from about 25% to about 50%, these differences between the two sectors may have had important implications on the macro-economy.

1.3 Model Details

In this section, I outline the details of the model. Nationally, representative households lend to institutional investors in the form of deposits, who then lend and monitor loans on both the deposit and the interbank markets. Firms are segmented on a continuum of islands, and produce final goods subject to island-specific shocks to effective capital. Each island has one representative retail bank and one representative wholesale bank. Both types of banks lend to firms on the same island with no friction and are subject to default. Due to an agency problem between institutional investors and the banks, banks of both types are subject to borrowing constraints.

1.3.1 Households

A representative household chooses C_t, D_t, and L_t to maximize

$$\sum_{t=0}^{\infty} \beta^t [u(C_t) - \nu(L_t)]$$

subject to budget constraint

$$C_t + D_t = W_t L_t + R^D_{t-1} D_{t-1} + \Pi_t$$

where C_t is consumption, D_t is household deposits in retail banks, and R^D_{t-1} is the riskless gross deposit interest rate. The household provides labor L_t for the production of final goods and earns wage W_t. Labor is perfectly mobile and thus the wage is equalized across islands. Π_t is dividend payments from household ownership of both wholesale and retail banks.

FOCs are:

$$E_t \Lambda_{t,t+1} R_t^D = 1 \tag{1.1}$$

$$W_t = \frac{\nu'(L_t)}{u'(C_t)} \tag{1.2}$$

where $\Lambda_{t,t+1} = \beta \frac{u'(C_{t+1})}{u'(C_t)}$.

1.3.2 Firms

Firms are perfectly competitive final goods producers segmented on islands $j \in [0,1]$ and subject to idiosyncratic shocks to effective capital.

On each island, firms are of either a "standard" or a "sub-standard" type, with idiosyncratic i.i.d. shocks $(\omega_t^j, \tilde{\omega}_t^j)$ respectively to their capital such that $(\omega_t^j K_t^j, \tilde{\omega}_t^j K_t^j)$ are the effective capital stocks used for production in period t. These shocks are island-specific, such that all firms of a given type on an island have the same productivity. Denote the cdf of these shocks as $F(\omega_t; \sigma_{t-1}) \equiv F_{t-1}(\omega)$ and $\tilde{F}(\tilde{\omega}_t; \sigma_{t-1}) \equiv \tilde{F}_{t-1}(\tilde{\omega})$ for the distribution of shocks to standard and substandard firms, respectively. σ_{t-1} is an exogenous process governing the time-t dispersion (standard deviation) for both the standard and substandard distributions and is known one period in advance (as of t-1). It is assumed that the means for both distributions are time-invariant, and that $\int \omega d\tilde{F}_t(\omega) = E(\tilde{\omega}) < \int \omega dF_t(\omega) = E(\omega) = 1$ (where the mean of the standard technology is normalized to one), such that substandard technology has a lower mean return and is thus inefficient.

Due to the constraints imposed on the banks on each island, the substandard firms do not operate in equilibrium (which will become clear shortly). I thus use notation for standard firms below to describe the firm's activities.

Each period firms take K_t^j and productivity levels (Z_t, ω_t^j) to be predetermined and choose L_t^j to maximize operating profit $Y_t^j - W_t L_t^j$ subject to production technology

$$Y_t^j = Z_t(\omega_t^j K_t^j)^\alpha (L_t^j)^{1-\alpha} \tag{1.3}$$

After solving this static problem, the firm's operating profit can be written as:

$$\alpha Z_t(\omega_t^j K_t^j)^\alpha (L_t^j)^{1-\alpha} \equiv R_t^K \omega_t^j K_t^j,$$

where the return on effective capital is defined as follows and depends only on aggregate conditions:

$$R_t^K \equiv \frac{\alpha Z_t(\omega_t^j K_t^j)^\alpha (L_t^j)^{1-\alpha}}{\omega_t^j K_t^j} = \alpha Z_t[\frac{(1-\alpha)Z_t}{W_t}]^{\frac{1-\alpha}{\alpha}} \tag{1.4}$$

Firms do not hold inside equity, and capital purchases at the beginning of period t are financed entirely by issuance of a number $A_{t-1}^{Wj} + A_{t-1}^{Rj}$ of external equity claims on the period-t cash flow (to wholesale and retail banks). Therefore:

$$K_t^j = A_{t-1}^{Wj} + A_{t-1}^{Rj} \tag{1.5}$$

After production each period, firms sell depreciated capital to capital producers at the price of one. Thus firms' total earnings in period t are:

$$[R_t^K + (1-\delta)]\omega^j K_t^j$$

which is paid off entirely to the financing banks.[3]

1.3.3 Bank Balance Sheet

There is one representative wholesale bank and one representative retail bank on each island. Both wholesale and retail banks lend to firms who invest in productive capital in the amount of A_t^{ij} each period, where $i = W, R$ stands for the two different types of banks. As firms use no internal equity financing, the gross return on bank assets in each period is therefore firms' total cash flow $(R_t^K + (1-\delta))\omega_t^j A_{t-1}^{ij}$. In addition, both types of banks incur a cost when managing firm assets in the amount of $\gamma^i \omega_t^j A_{t-1}^{ij}$, proportional to the size of their respective loans to the firms ($0 < \gamma^i < 1$, for $i = W, R$). Therefore, banks' return on assets from period t-1 is thus $R_t^i \omega_t^j$, where:

$$R_t^i \equiv R_t^K + (1-\delta) - \gamma^i \tag{1.6}$$

for both retail and wholesale banks. R_t^i is equal across islands.

There is a representative, perfectly competitive institutional investor that channels funds among agents and monitors loans. The institutional investor col-

[3] The assumption that banks receive all firms' asset returns follows Gertler and Kiyotaki (2010). The idea is to capture the uncertainty of bank asset returns, rather than focusing on whether bank assets are in the form of equity or debt. To quote from their paper: "banks lend frictionlessly to firms of the same island against their future profits. In this regard, firms are able to offer banks perfectly state-contingent debt. It is simplest to think of the banks' claim on firms as equity."

lects funds on both the deposit market and the interbank market, and makes loans to borrowing banks of either type. Specifically, each period on the deposit market, the institutional investor collects deposits from the households D_t, pays them back at the riskless interest rate R_t^D, and invests in and monitors the banks on behalf of the households. On the deposit market, the investor makes loans to banks: $D_t^{ij} \geq 0$. On the interbank market, the institutional investor collects or makes loans in the amount of B_t^{ij} from the banks, where $\sum_{ij} B_t^{ij} = 0 \ \forall t$ in equilibrium.

When borrowing on the interbank market, banks agree to pay back a non-state contingent amount of $\bar{B}_t^{ij}$ at the beginning of period t+1 for loans made at the beginning of period t in the amount of B_t^{ij} . When borrowing from the institutional investor on the deposit market, bank i on island j borrows D_t^{ij} at the beginning of period t, and pays back $D_t^{ij} R_t^{Di}$ at the beginning of the next period, where the deposit return from a particular type of banks is equal across islands. Since retail banks are commercial banks with access to household deposits and deposit insurance, they are able to pay back at the risk-free rate: $R_t^{DR} = R_t^D$. For wholesale banks, due to the lack of public insurance, there is a heightened level of risk associated with borrowing on the deposit market compared to the retail banks, so that $R_t^{DW} > R_t^D$. Hence in equilibrium the wholesale bank does not borrow on the deposit market ($D_t^{Wj} = 0 \quad \forall t \forall j$) and is a net borrower on the interbank market: $B_t^{Wj} > 0$. The retail bank is a net borrower on the deposit market and a net lender on the interbank market, i.e. $D_t^{Rj} > 0, B_t^{Rj} < 0$.

At the beginning of period t, the net earnings of bank j of type i from operations in t-1 are the gross return on assets minus debt payments:

$$N_t^{ij} = A_{t-1}^{ij} R_t^i \omega_t^j - \bar{B}_{t-1}^{ij} - D_{t-1}^{ij} R_{t-1}^{Di} \tag{1.7}$$

The bank defaults if $N_t^{ij} \leq 0$, in which case the investor takes the bank's remaining assets $A_{t-1}^{ij} R_t^i \omega_t^j$. Bank default thus depends on the idiosyncratic shock to firms' return on capital — a bank will default if

$$\omega_t^j \leq \frac{\bar{B}_{t-1}^{ij} + D_{t-1}^{ij} R_{t-1}^{Di}}{A_{t-1}^{ij} R_t^i} \equiv \bar{\omega}_t^{ij} \tag{1.8}$$

To reflect the regulation of the interbank market I assume that wholesale banks bear an extra μ fraction of the loan payment as the cost of engaging with institutional investors (henceforth referred to as "financing cost"), where $0 \leq \mu < 1$. When regulation on interbank market is significant, the wholesale banks end up with a lower beginning-of-period net worth after repaying the interbank borrowing of the previous period:

$$N_t^{Wj} = A_{t-1}^{Wj} R_t^W \omega_t^j - (1+\mu)(\bar{B}_{t-1}^{Wj} + D_{t-1}^{Wj} R_{t-1}^{DW}) \tag{1.9}$$

In addition to the possibility of default, there is an exogenous probability $(1-\theta^i)$ (i = W,R) of exit each period for each non-defaulting wholesale or retail bank. Upon exit the net worth accumulated in each bank reverts to the household (after banks repay their debt obligations). This assumption is standard in the literature and ensures the existence of debt financing in the long-run equilibrium.

If bank j of type i continues to operate (non-defaulting and non-exiting), it decides the amount of assets (lending to firms) and the amount of debt to take on given its net worth (N_t^{ij}). The balance sheet constraint is thus:

$$N_t^{ij} + B_t^{ij} + D_t^{ij} = A_t^{ij} \tag{1.10}$$

where internal equity and debt are used to finance loans to the firms.

Given that the bank pays dividends only when it exits, the objective of the bank at the beginning of period t is to maximize the expected present value of future dividends. For each continuing bank (non-defaulting and non-exiting) in period t, the value function is:

$$V_t^i(N_t^{ij}) = E_t \sum_{k=1}^{\infty} \Lambda_{t,t+k}(1-\theta^i)(\theta^i)^{k-1} \int_{\bar{\omega}_{t+k}^{ij}} N_{t+k}^{ij} dF_t(\omega) \tag{1.11}$$

where $\Lambda_{t,t+k}$ is the stochastic discount factor, which is equal to the marginal rate of substitution between consumption of date t+k and date t of the representative household. Since exiting banks retain their net worth only when they have not defaulted in the same period, the rebated dividend is the net worth value conditional on $\omega \geq \bar{\omega}_{t+k}^{ij}$. For simplicity of notation I still use N_{t+k}^{ij} to denote the integrand *before* the realization of ω, e.g., it denotes $N_{t+k}^{ij} = A_{t+k-1}^{ij} R_{t+k}^{i} \omega - \bar{B}_{t+k-1}^{ij} - D_{t+k-1}^{ij} R_{t+k-1}^{Di}$ whose value depends on the realization of ω.

The recursive representation of the bank's objective is then:

$$V_t^i(N_t^{ij}) = \max E_t\Lambda_{t,t+1}\int_{\bar{\omega}_{t+1}^{ij}}[\theta^i V_{t+1}^i(N_{t+1}^{ij}) + (1-\theta^i)(N_{t+1}^{ij})]dF_t(\omega) \tag{1.12}$$

subject to equations (1.7)-(1.9), where $\Lambda_{t,t+1} = \beta\frac{u'(C_{t+1})}{u'(C_t)}$ and i=W,R. The bank takes as given the beginning-of-period net worth N_t^{ij} and chooses A_t^{ij}, $\bar{B}_t^{ij}$ and D_t^{ij}.

1.3.4 Bank Constraints

It is assumed that all investors (represented by the institutional investor) are able to invest in the form of deposits with a guaranteed risk-free rate of return. As such, the banks face a participation constraint imposed by the investor, where the expected payoff on bank debt has to be higher than that from investing the same amount in an asset paying the risk-free rate R_t^D.

$$E_t\Lambda_{t,t+1}\{R_{t+1}^i A_t^{ij}\int^{\bar{\omega}_{t+1}^{ij}}\omega dF_t(\omega)+(\bar{B}_t^{ij}+D_t^{ij}R_t^{Di})[1-F_t(\bar{\omega}_{t+1}^{ij})]\} \geq E_t\Lambda_{t,t+1}R_t^D(B_t^{ij}+D_t^{ij}) \tag{1.13}$$

In addition to the participation constraint, there is an incentive for both the wholesale bank and the retail bank to invest in substandard firms springing from a risk-shifting moral hazard problem as in Adrian and Shin (2013). Banks have an incentive to invest inefficiently due to limited liability associated with the risky debt contract on their liability side. Limited liability implies that the bank enjoys the upside risk in asset returns but does not bear the downside risk, which is ultimately borne by interbank or deposit market investors when banks default.

Specifically, we make two assumptions about the distributions of idiosyncratic returns on assets for standard and substandard firms on each island:

Assumption 1: $\int \omega d\tilde{F}_t(\omega) < \int \omega dF_t(\omega) \Rightarrow E(\tilde{\omega}) < E(\omega)$

Assumption 2: There exists a ω_t^* such that $F_t(\omega_t^*) = \tilde{F}_t(\omega_t^*)$ and $(F_t(\omega) - \tilde{F}_t(\omega))(\omega - \omega_t^*) > 0$ for all $\omega > 0$.

We know that the net expected return from investing in the standard asset for either type of bank is:

$$R_{t+1}^i A_t^{ij} \int_{\bar{\omega}_{t+1}^{ij}} (\omega - \bar{\omega}_{t+1}^{ij}) dF_t(\omega) = R_{t+1}^i A_t^{ij} \{E(\omega) + \int^{\bar{\omega}_{t+1}^{ij}} (\bar{\omega}_{t+1}^{ij} - \omega) dF_t(\omega) - \bar{\omega}_{t+1}^{ij}\}.$$

Banks' expected return on their assets thus depends positively on both the mean value of the return on firm assets $E(\omega)$ as well as the expected losses transferred onto their creditors in the event of default $\int^{\bar{\omega}_{t+1}^{ij}} (\bar{\omega}_{t+1}^{ij} - \omega) dF_t(\omega)$.

Under Assumption 1 we have that the substandard investment has a lower mean return: $E(\tilde{\omega}) < E(\omega)$.

Using integration by parts, it can be shown that:

$$\int^{\bar{\omega}_{t+1}^{ij}} (\bar{\omega}_{t+1}^{ij} - \omega) d\tilde{F}_t(\omega) - \int^{\bar{\omega}_{t+1}^{ij}} (\bar{\omega}_{t+1}^{ij} - \omega) dF_t(\omega) = \int^{\bar{\omega}_{t+1}^{ij}} (\tilde{F}_t(\omega) - F_t(\omega)) d\omega,$$

and that:

$$\lim_{\bar{\omega}\to 0}\{\int^{\bar{\omega}_{t+1}^{ij}}(\bar{\omega}_{t+1}^{ij}-\omega)d\tilde{F}_t(\omega)-\int^{\bar{\omega}_{t+1}^{ij}}(\bar{\omega}_{t+1}^{ij}-\omega)dF_t(\omega)\}>0.$$

Together with Assumption 2, these two equations mean that the difference in losses transfered between investing in substandard and standard firms (the second term in expected net return) is strictly increasing in the realization of island-specific shock $\bar{\omega}$ for $\bar{\omega}<\omega_t^*$, reaches a maximum at ω_t^*, and then is strictly decreasing for $\bar{\omega}>\omega_t^*$, but is always positive.

This implies that banks face a trade-off between a higher mean return and a lower benefit from transferred losses when choosing between standard and substandard firms. However, when banks borrow beyond a certain level, the benefit of investing in substandard firms in terms of higher transferred losses starts to outweigh the associated lower mean returns, and banks thus have an incentive to invest inefficiently and transfer losses to investors. Namely the banks are tempted to invest in substandard technology regardless of its lower expected return. This will be further illustrated in Section 1.4 in more detail.

Investors know about this incentive on the bank's part and thus impose an incentive compatibility constraint to make sure risk shifting doesn't happen. By extending lending only if the incentive constraint is satisfied, the creditors limit the debt value loaned to the banks and consequently the leverage of the banks.

The banks therefore face an incentive constraint imposed by the lenders in addition to the participation constraint, where the amount banks can borrow is limited so that the expected payoff from financing standard firms is higher than that from financing inefficient firms.

$$E_t\Lambda_{t,t+1}\int_{\bar{\omega}^{ij}_{t+1}}\{\theta^i V^i_{t+1}(N^{ij}_{t+1})+(1-\theta^i)(N^{ij}_{t+1})\}dF_t(\omega)$$

$$\geq E_t\Lambda_{t,t+1}\int_{\bar{\omega}^{ij}_{t+1}}\{\theta^i V^i_{t+1}(\tilde{N}^{ij}_{t+1})+(1-\theta^i)(\tilde{N}^{ij}_{t+1})\}d\tilde{F}_t(\omega) \tag{1.14}$$

for i=R,W; and where $\tilde{N}^{ij}$ denotes bank ij's net worth when investing in substandard assets.

While both wholesale and retail banks face the same incentive constraint, I assume that this constraint is more strictly implemented for the wholesale banks due to better monitoring skills as well as higher sensitivity to market conditions of the interbank investors compared to households, even though both flows are intermediated by the institutional investor. For this purpose I introduce parameters $0 < \chi^i \leq 1$, i = R, W, such that when investing in substandard technology, the actual returns to the banks on substandard firm assets A^{ij}_{t-1} are subject to a cost of $(1-\chi^i)$ and are thus $\chi^i R^A_t A^{ij}_{t-1}\omega^j_t$. Namely, the net worth of bank j of type i when investing in substandard firms would be $\tilde{N}^{ij}_{t+1} = \chi^i A^{ij}_t R^i_{t+1}\omega^j_{t+1} - \bar{B}^{ij}_t - D^{ij}_t R^{Di}_t$. In addition, I assume $\chi^W < \chi^R = 1$ such that the incentive constraint is more severe for the wholesale banks. Consequently, in response to disturbances in asset returns, wholesale banks experience a sharper change in their borrowing capacities compared to retail banks.

Because of these constraints on wholesale banks' borrowing capacity, retail banks are still able to operate even in an economy where the wholesale banking sector is more efficient and enjoys a higher return on assets.

1.3.5 Capital Producer

A representative capital producer buys depreciated capital from firms, buys final goods to invest in new capital, produces new capital with a one for one technology and sells new capital to firms. The price of capital is one and capital producers make no profit in equilibrium.

Aggregate capital supply thus evolves according to:

$$K_{t+1} = I_t + (1 - \delta) K_t.$$

1.3.6 Timeline of Events

Before presenting more details of the model, I summarize a timeline of the events described so far.

At the end of each period t-1, the state of the economy relevant for banks includes: debt repayments due $\bar{B}^{ij}_{t-1}$, D^{ij}_{t-1}, and bank holdings of firm assets A^{ij}_{t-1}.

At the beginning of period t, *the production stage* takes place. The aggregate productivity Z_t is revealed and the idiosyncratic shock to firm capital ω^j_t on each island is realized. Given these, the firms choose labor input and production takes place on each island: $Y^j_t = Z_t(\omega^j_t K^j_t)^{\alpha}(L^j_t)^{1-\alpha}$. As a result, the return on effective capital R^K_t is determined and the return on bank assets and $R^i_t \omega^j_t$ are realized (where

$R_t^i = R_t^K + (1-\delta) - \gamma^i$ and $R_t^K = \alpha Z_t[\frac{(1-\alpha)Z_t}{W_t}]^{\frac{1-\alpha}{\alpha}}$).

Next, *the lending stage* takes place for period t. Banks' returns on firm assets are now fully revealed: $A_{t-1}^{ij} R_t^i \omega_t^j$. Each bank's net worth is therefore determined, which is the state variable for their period t optimization problem. Given repayment obligations and bank net worth, both wholesale and retail banks learn their default status. For the non-defaulting banks, it is at this stage that $(1-\theta^i)$ of them exit. The non-defaulting and non-exiting banks are the "continuing banks" who will make lending/borrowing decisions in period t. The continuing banks choose firm loans A_t^{ij}, interbank loan contracts B_t^{ij} and $\bar{B}_t^{ij}$, and deposit debt amounts D_t^{ij}. The firms then use bank loans to purchase capital K_{t+1}^j from the capital producer for next-period production, which concludes the stream of events in period t.

1.3.7 Aggregation

For both types of banks $i = W, R$, the net worth of non-defaulting banks is $N_t^{ij} = R_t^i A_{t-1}^{ij}(\omega_t^j - \bar{\omega}_t^j)$ where we have used the result that $\bar{\omega}_t^{ij} = \bar{\omega}_t^i \forall j$ from the bank problem (see Appendix for proof).[4] Define $A_{t-1}^i \equiv \int_0^1 A_{t-1}^{ij} dj$. Then aggregating across islands we have: $N_t^{i,nondefault} = R_t^i A_{t-1}^i \int_{\bar{\omega}_t^i}(\omega - \bar{\omega}_t^i) dF_{t-1}(\omega)$. A fraction θ^i of the non-defaulting banks continue to operate, and banks that default or exit are replaced by an equal number of new banks, $1 - \theta^i[1 - F_{t-1}(\bar{\omega}_t^i)]$. Following Gertler, Kiyotaki and Prestipino (2016), new banks enter with an endowment W^j that is received only in the first period of life. This initial endowment may be thought of as

[4]In the proof of the bank problem, it is shown that in equilibirum, the bank's value function is linear in bank's net worth, and that all constraints are binding. In the binding incentive constraint equation, as a result of linearity, the default threshould is a function of only non-island-specific variables.

the start up equity for the new banker. Therefore, $N_t^{i,new} = (1-\theta^i[1-F_{t-1}(\bar{\omega}_t^i)])W^i$.

Aggregate net worth of type i banks at the end of period t is therefore:

$$N_t^i = \theta^i N_t^{i,nondefault} + N_t^{i,new} = \theta^i R_t^i A_{t-1}^i \int_{\bar{\omega}_t^i} (\omega - \bar{\omega}_t^i) dF_{t-1}(\omega) + (1-\theta^i)[1-F_{t-1}(\bar{\omega}_t^i)]W^i \tag{1.15}$$

In addition, the aggregate leverage ratios for wholesale and retail banks are defined as the ratios of aggregate assets over aggregate net worth: [5]

$$A_t^i = \phi_t^i N_t^i \tag{1.16}$$

The total equity and aggregate leverage of the economy are defined as:

$$N_t = N_t^W + N_t^R \tag{1.17}$$

$$\phi_t = (A_t^W + A_t^R)/(N_t^W + N_t^R) = K_t/N_t. \tag{1.18}$$

[5] For the case of retail banks, A_t^R is strictly speaking their assets invested in firms only. As they also have assets in the form of lending to wholesale banks, their total assets are $A_t^R + B_t^R$. Their total leverage is correspondingly $(A_t^R + B_t^R)/N_t^R$ whereas A_t^R/N_t^R is the part of leverage that is due to firm investment. In the quantitative exercises, wherever applicable, I use the definition that corresponds with the empirical counterparts.

1.3.8 Market Clearing

The following markets clear in equilibrium.

Aggregate capital demand equals aggregate supply:

$$\int_0^1 K_t^j dj = K_t \tag{1.19}$$

Aggregate demand for bank assets equals aggregate supply:

$$K_{t+1} = \sum_i A_t^i, \quad i = W, R \tag{1.20}$$

Labor markets clear:

$$\int_0^1 L_t^j dj = (\frac{(1-\alpha)Z_t}{W_t})^{1/\alpha} \int_0^1 \omega_t^j K_t^j dj = (\frac{(1-\alpha)Z_t}{W_t})^{1/\alpha} K_t = L_t \tag{1.21}$$

The aggregate supply of final goods satisfies $\bar{Y}_t = \int_0^1 Y_t^j dj = Z_t K_t^\alpha L_t^{1-\alpha}$, and the gross total output is:

$$Y_t = Z_t K_t^\alpha L_t^{1-\alpha} + \sum_i (1-\theta^i)[1 - F_{t-1}(\bar{\omega}_t^i)])W^i \tag{1.22}$$

The market for final goods clears:

$$Y_t = C_t + I_t + \sum_i \gamma^i A_{t-1}^i + \mu(\bar{B}_{t-1}^W + D_{t-1}^W R_{t-1}^{DW}), \quad i = W, R \tag{1.23}$$

Markets for deposits and interbank loans clear:

$$\sum_{i} \int_{0}^{1} D_t^{ij} dj = D_t, \quad i = W, R \tag{1.24}$$

$$\sum_{i} \int_{0}^{1} B_t^{ij} dj = 0, \quad i = W, R \tag{1.25}$$

1.4 Model Equilibrium

1.4.1 Growth of the Wholesale Banks

The steady state share of wholesale banking assets in the model is defined as: $\frac{A^W}{A^R+A^W}$. [6] In the result section, I show that the decrease of both the financing cost as well as the cost of asset management for the wholesale banks increase wholesale banks' asset share in the steady state. Below I show analytically how these two factors work to expand wholesale banking assets in equilibrium.

First, Appendix A.2 proves that, under reasonable parameter assumptions, the equilibrium dynamics of the banks are characterized by the following two equations. First, the incentive constraint holds with equality for both the wholesale banks and the retail banks:

$$E(\omega) - \chi^i E(\tilde{\omega}) =$$

$$E_t\{\frac{\Lambda_{t,t+1}R^A_{t+1}[\theta^i\lambda^i_{t+1}+1-\theta^i]}{E_t\Lambda_{t,t+1}R^A_{t+1}[\theta^i\lambda^i_{t+1}+1-\theta^i]}[\chi^i\int^{\bar{\omega}^i_{t+1}/\chi^i}(\bar{\omega}^i_{t+1}/\chi^i-\omega)d\tilde{F}_t(\omega)-\int^{\bar{\omega}^i_{t+1}}(\bar{\omega}^i_{t+1}-\omega)dF_t(\omega)]\} \tag{1.26}$$

where $\bar{\omega}^i_{t+1} = \bar{\omega}^{ij}_{t+1}\forall j$, and $\lambda^i_{t+1} = \lambda^{ij}_{t+1}\forall j$ is the Lagrange multiplier for the incentive constraint in the bank's problem.

Second, the participation constraint holds with equality for both types of banks:

[6] Since in equilibirum $B^W = -B^R > 0$, wholesale bank asset share can also be defined as $\frac{A^W}{A^R+A^W+B^W}$ to include interbank assets on the retail banks' balance sheet. These two measures are positively correlated.

$$E_t\Lambda_{t,t+1}R^i_{t+1}A^{ij}_t\{\int^{\bar{\omega}^i_{t+1}}\omega dF_t(\omega)+\bar{\omega}^i_{t+1}[1-F_t(\bar{\omega}^i_{t+1})]\}=A^{ij}_t-N^{ij}_t \qquad (1.27)$$

where $\bar{\omega^i}_{t+1}=\bar{\omega^{ij}}_{t+1}\forall j$.

- **Decreasing financing cost:**

When it becomes easier to borrow from the institutional investors, for example due to the deregulation of the interbank market, μ decreases in the equation $N^{Wj}_t = A^{Wj}_{t-1}R^W_t\omega^j_t-(1+\mu)(\bar{B}^{Wj}_{t-1}+D^{Wj}_{t-1}R^{DW}_{t-1})$ for wholesale banks. This increases wholesale banks' net worth and borrowing capacity in the next period. Re-arranging equation (1.27) (for wholesale banks), bank assets in steady state are positively correlated with bank net worth:

$$A^W=\frac{N^W}{1-\beta R^W\{\int^{\bar{\omega}^W}\omega dF_t(\omega)+\bar{\omega}^W[1-F_t(\bar{\omega}^W)]\}}.$$

Therefore, a decreased financing cost increases steady state wholesale bank assets. As the financing cost does not affect retail banking balance sheets, a lower financing cost in turn increases the steady state share of wholesale bank assets $\frac{A^W}{A^R+A^W}$.

- **Decreasing management cost:**

From equation (1.15), aggregate net worth of type i banks at the end of period t is:

$$N_t^i = \theta^i R_t^i A_{t-1}^i \int_{\bar{\omega}_t^i} (\omega - \bar{\omega}_t^i) dF_{t-1}(\omega) + (1-\theta^i)[1 - F_{t-1}(\bar{\omega}_t^i)] W^i.$$

Combining equation (1.15) and equation (1.27), we can write steady state bank assets as:

$$A^i = \frac{(1-\theta^i)[1-F(\bar{\omega}^i)]W^i}{1 - R^i\{\beta\{\int^{\bar{\omega}^i} \omega dF_t(\omega) + \bar{\omega}^i[1 - F_t(\bar{\omega}^i)]\} + \theta^i \int_{\bar{\omega}^i} (\omega - \bar{\omega}^i) dF(\omega)\}}.$$

This equation shows that in steady state, bank assets A^i are positively correlated with the return on assets R^i for both retail and wholesale banks. When there is a decrease in the management cost γ^W, wholesale banks' return on assets increases: $R^W = \alpha \bar{Z}[\frac{(1-\alpha)\bar{Z}_t}{W}]^{\frac{1-\alpha}{\alpha}} + (1-\delta) - \gamma^W = \alpha Y/K + (1-\delta) - \gamma^W$. This increase in R^W in turn leads to an increase in A^W. Since this change affects only the wholesale banks, the steady state share of wholesale banking assets increases.

1.4.2 Risk Shock, Bank Constraints, and Bank Leverage Ratios

Here I describe how the constraints faced by banks work to affect their leverage ratios in equilibrium.

As mentioned in the previous section, the bank's net expected return on firm assets (suppressing superscript i for either retail or wholesale banks) is: $R_{t+1} A_t^j \int_{\bar{\omega}_{t+1}^j} (\omega - \bar{\omega}_{t+1}^j) dF_t(\omega) = R_{t+1} A_t^j \{E(\omega) + \int^{\bar{\omega}_{t+1}^j} (\bar{\omega}_{t+1}^j - \omega) dF_t(\omega) - \bar{\omega}_{t+1}^j\}$, in which $\int^{\bar{\omega}_{t+1}^j} (\bar{\omega}_{t+1}^j - \omega) dF_t(\omega)$ is the expected losses transferred onto their creditors in the event of default. Define the expected loss transfered from investing in standard firms as:

$$\pi(\bar{\omega}^j_{t+1};\sigma_t) \equiv \int^{\bar{\omega}^j_{t+1}} (\bar{\omega}^j_{t+1} - \omega) dF_t(\omega),$$

where σ_t is an exogenous process governing the standard deviation for both distributions.

Correspondingly, the expected loss transferred when investing in substandard firms is

$\int^{\bar{\omega}^j_{t+1}/\chi} (\bar{\omega}^j_{t+1} - \chi\omega) d\tilde{F}_t(\omega)$, which we rewrite as:

$$\chi\tilde{\pi}(\bar{\omega}^j_{t+1}/\chi;\sigma_t) \equiv \chi \int^{\bar{\omega}^j_{t+1}/\chi} (\bar{\omega}^j_{t+1}/\chi - \omega) d\tilde{F}_t(\omega).$$

We can then define the gain in left tail risk from investing in substandard firms as:

$$\Delta\pi(\bar{\omega}^j_{t+1};\sigma_t) \equiv \chi\tilde{\pi}(\bar{\omega}^j_{t+1}/\chi;\sigma_t) - \pi(\bar{\omega}^j_{t+1};\sigma_t).$$

As mentioned in the previous subsection, Appendix A.2 proves that, in equilibrium, the incentive constraint as well as the participation constraint hold with equality for both the wholesale banks and the retail banks, as characterized by equations (1.26) and (1.27). Note that in steady state, the incentive constraint for either retail or wholesale banks (equation (1.26)) can then be written as:

$$E(\omega) - \chi E(\tilde{\omega}) = \chi\tilde{\pi}(\bar{\omega}^j/\chi;\sigma) - \pi(\bar{\omega}^j;\sigma) = \Delta\pi(\bar{\omega}^j;\sigma). \tag{1.28}$$

where we have used $\int_{\bar{\omega}^j_{t+1}}(\omega - \bar{\omega}^j_{t+1})dF_t(\omega) = E(\omega) + \int^{\bar{\omega}^j_{t+1}}(\bar{\omega}^j_{t+1} - \omega)dF_t(\omega) - \bar{\omega}^j_{t+1}$.

We now make three further assumptions on the distributions of the island-specific shocks (when $\chi \leq 1$).[7]

Assumption 3:

$$\frac{\partial \chi \tilde{\pi}(\bar{\omega}/\chi; \sigma)}{\partial \sigma} > \frac{\partial \pi(\bar{\omega}; \sigma)}{\partial \sigma} > 0 \quad \Rightarrow \frac{\partial \Delta\pi(\bar{\omega}; \sigma)}{\partial \sigma} > 0$$

Assumption 4:

$$\frac{\partial \Delta\pi(\bar{\omega}; \sigma)}{\partial \chi} > 0$$

Assumption 5:

$$\frac{\partial^2 \Delta\pi(\bar{\omega}; \sigma)}{\partial \sigma \partial \bar{\omega}} > 0$$

These assumptions are relatively weak (easy to satisfy). Assumption 3 implies that, following an increase in the dispersion of island-specific shocks, downside risk goes up for both types of firms but does so more for the substandard firms. Assumption 4 says that when parameter χ goes down in value, so does $\Delta\pi(\bar{\omega}; \sigma)$, which means that the additional downside risk associated with substandard technology is lower for the wholesale banking sector (as $\chi^W < \chi^R$) than the retail sector. This translates into a higher $\bar{\omega}$ for the wholesale sector for a given level of $\Delta\pi(\bar{\omega}; \sigma)$, the difference in downside risk (as will become clear shortly). Finally, Assumption 5

[7] In the quantitative exercise in the next section, the distribution of island-specific shocks is chosen to be log-normal for both the standard and substandard technology: $log\omega \overset{iid}{\sim} N(\frac{-\sigma_t^2}{2}, \sigma_t^2)$, $log\tilde{\omega} \overset{iid}{\sim} N(\frac{-\eta\sigma_t^2 - \psi}{2}, \eta\sigma_t^2)$, where $\psi > 0$ and $\eta > 1$. This specification ensures that Assumptions 1, 2, 3, 4, and 5 are satisfied.

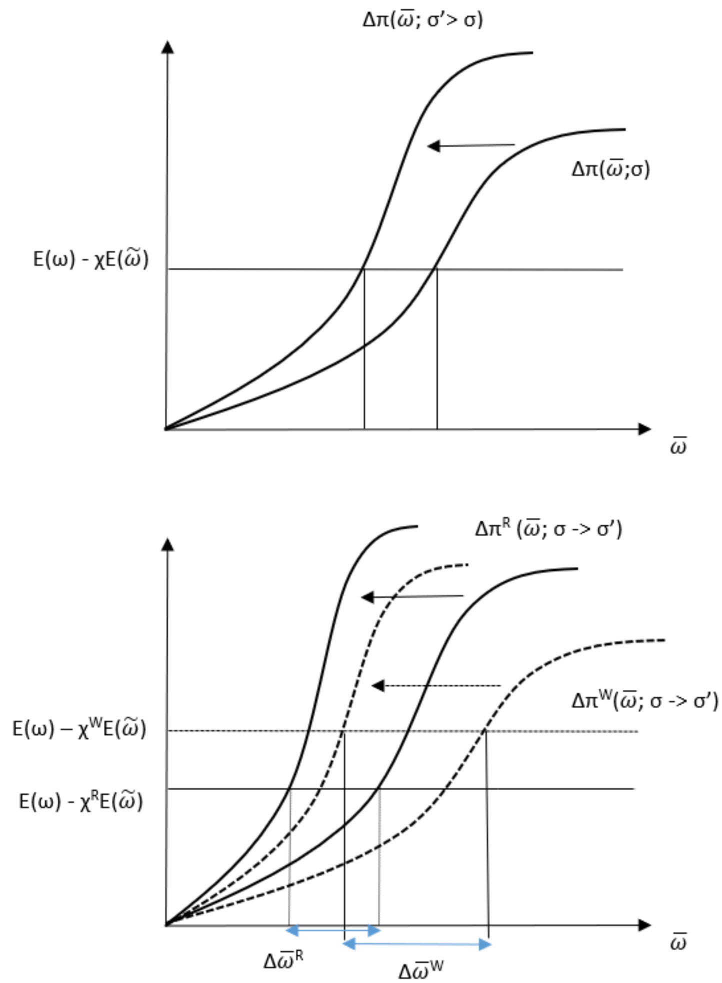

Figure 1.11: An Increase in σ, Incentive Constraints

says that the difference in the change of downside risk following an increase in the dispersion of island-specific shocks is more significant at higher levels of $\bar{\omega}$.[8]

Under these assumptions, an increase in σ_t induces a reduction in the leverage ratios of both retail and wholesale banks, but the reduction is more for wholesale banks. This can be illustrated by a mechanism sketched in Figure 1.11 and Figure 1.12.

The two plots in Figure 1.11 represent the steady-state incentive constraint

[8] Assumptions 4 and 5 together imply $\frac{\partial^2 \Delta\pi(\bar{\omega};\sigma)}{\partial\sigma\partial\chi} > 0$.

as in equation (1.28), which says the loss in expected mean return should equal the expected gain in transferred loss when investing in substandard firms. The intersection of the horizontal line $E(\omega)-\chi E(\tilde{\omega})(=1-\chi E(\tilde{\omega}))$ and the upward-sloping curve $\Delta\pi(\bar{\omega};\sigma)$ (as $\frac{\partial\Delta\pi(\bar{\omega};\sigma)}{\partial\bar{\omega}}>0$) then gives the equilibrium default threshold $\bar{\omega}$ (on the horizontal axis). The upper subplot shows what happens to the incentive constraint when there is an increase in the standard deviation of island-specific shocks σ for either type of bank. Under Assumption 3, *ceteris paribus* the $\Delta\pi(\bar{\omega};\sigma)$ schedule rotates upwards/to the left and as a result the equilibirium $\bar{\omega}$ goes down. Intuitively, higher volatility makes it more attractive for the banks to invest inefficiently. The investors reduce the level of credit provided to banks to discourage the banks from doing so, which translates into a lower debt repayment obligation and thus a lower default threshold.

The lower subplot of Figure 1.11 shows the difference in this change of $\bar{\omega}$ due to an increase in σ between retail and wholesale banks. The solid lines represent the incentive constraints of the retail banks whereas the dashed lines represent those of the wholesale banks. Since wholesale banks have a lower χ, the horizontal line representing the difference in mean return is shifted up compared to retail banks (from the solid line to the dashed line). This alone creates a larger drop in $\bar{\omega}$ when there is an increase in σ . Furthermore, under Assumptions 4 and 5, a lower χ means that the $\Delta\pi(\bar{\omega};\sigma)$ schedule rotates down/to the right for each σ level for wholesale banks, resulting in a higher level of $\bar{\omega}$. When σ increases, the shift of the $\Delta\pi(\bar{\omega};\sigma)$ schedule is bigger for higher levels of $\bar{\omega}$. This makes the difference in equilibirum $\bar{\omega}$ between the low σ state and the high σ state higher for wholesale banks even for the same level of $E(\omega) - \chi E(\tilde{\omega})$. Thus, these two factors combined make the drop in $\bar{\omega}$ induced by an increase in σ more significant for wholesale banks than it is for retail banks as a result of lower χ.

To see how the same increase in σ affects the leverage ratios of the banks, define $\phi_t^{ij} \equiv A_t^{ij}/N_t^{ij}$, and note that the participation constraint of the banks (equation(1.27)) can be written as:

$$\phi_t^{ij} = A_t^{ij}/N_t^{ij} = \frac{1}{1 - E_t \Lambda_{t,t+1} R_{t+1}^i [\int^{\bar{\omega}_{t+1}^i} \omega dF_t(\omega) + \bar{\omega}_{t+1}^i (1 - F_t(\bar{\omega}_{t+1}^i))]}$$

$$= \frac{1}{1 - E_t \Lambda_{t,t+1} R_{t+1}^i [\bar{\omega}_{t+1}^i - \pi(\bar{\omega}_{t+1}^i; \sigma_t)]} = \phi_t^i \quad \forall j. \tag{1.29}$$

Figure 1.12 plots the leverage ratio as a function of $\bar{\omega}$ according to the participation constraint. An increase in σ affects the bank leverage ratio in two ways that can be seen clearly from equation (1.29). First, as stated in Assumption 3, a higher σ leads to higher $\pi(\bar{\omega}; \sigma)$, which shifts the participation constraint curve downward. Second, an increase in σ also causes a drop in $\bar{\omega}$, which further pushes down the leverage ratio along the participation constraint curve. Additionally, when increased volatility causes a drop in the default threshold that is more drastic for wholesale than for retail banks, it decreases the leverage ratio more for wholesale banks than for retail banks. Intuitively, downside risk $\pi(\bar{\omega}; \sigma)$ is higher when the cross-sectional return on assets becomes more uncertain (a higher σ, or equivalently a higher level of dispersion). The investors therefore have a lower expected payoff and decrease the amount of investment in the banks.

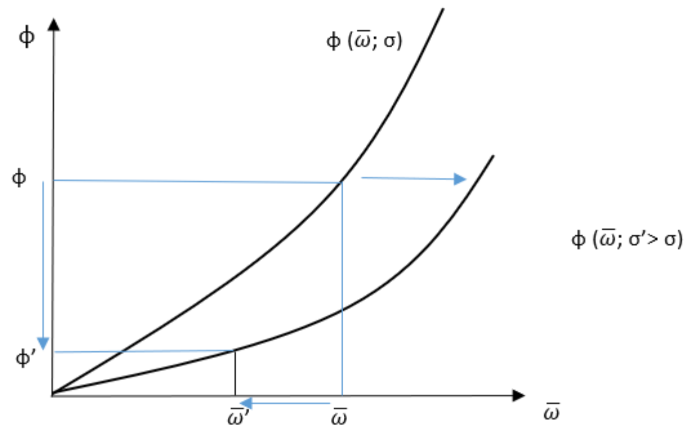

Figure 1.12: An Increase in σ, Participation Constraints

1.5 Growth of Wholesale Banking

In my first set of quantitative analyses, I focus on the mechanism of wholesale banking growth and its consequences. To do so I isolate the effect of the two parameters that can lead to wholesale banking growth in my model by changing the values of only these two parameters, one by one. First is the cost of asset management for the wholesale banks (a decrease in γ^W), which represents improved efficiency of wholesale banks over this period of time. The second factor is the decreased financing cost (a decrease in μ), reflecting the increased ease of engaging in the interbank market for the wholesale banks as a result of gradual deregulation in the banking industry and increasing regulatory arbitrage in the three decades preceding the financial crisis.

1.5.1 Functional Forms

The utility functions of the household are as follows:

$$u(C) = log(C),\ \nu(L) = \frac{L^{1+\varphi}}{(1+\varphi)}.$$

The TFP process is assumed to be AR(1) in logs:

$$log(Z_t/\bar{Z}) = \rho_z log(Z_{t-1}/\bar{Z}) + \epsilon_t^z$$

where $\bar{Z}$ is the steady state value and where $\epsilon_t^z \overset{iid}{\sim} N(0, \sigma_z^2)$.

The distribution of island-specific shocks is chosen to be log-normal for both the efficient and the substandard technology:

$$log\omega \overset{iid}{\sim} N(\frac{-\sigma_t^2}{2}, \sigma_t^2), \quad log\tilde{\omega} \overset{iid}{\sim} N(\frac{-\eta\sigma_t^2 - \psi}{2}, \eta\sigma_t^2)$$

where $\psi > 0$ and $\eta > 1$. We thus have

$$F(\omega; \sigma_t) = \Phi(\frac{log\omega + \sigma_t^2/2}{\sigma_t})$$

where $\Phi(\cdot)$ is the standard normal cdf. The distribution for the substandard technology $\tilde{F}$ is analogously defined. These functional forms are consistent with Assumptions 1 through 5 used in the model.

The standard deviation (volatility) of the island-specific shocks to standard firms is assumed also to follow an AR(1) process:

$$log(\sigma_t/\sigma) = \rho_\sigma log(\sigma_{t-1}/\sigma) + \epsilon_t^\sigma$$

where σ is the steady state standard deviation and $\epsilon_t^\sigma \overset{iid}{\sim} N(0, \sigma_\sigma^2)$.

1.5.2 Steady State Economies

I calibrate the benchmark model to the U.S. economy on the eve of the financial crisis in 2007, which I refer to as the "later" economy. I also calibrate two other economies, which I label as "earlier" and "intermediate" economies to present the different stages of the economy with a growing wholesale sector up until 2007. The share of wholesale bank assets (as a percentage of the total assets of the banking sector) in the earlier and later economies are calibrated to reflect roughly the share of wholesale assets in the data in the early 1980s and around 2007, respectively. The intermediate economy departs from the earlier economy only in terms of a decrease in financing cost (a decrease in μ); and the later economy departs from the intermediate economy only in terms of a decreased cost of wholesale asset management (a decrease in γ^W). In other words, all parameters are calibrated to be the same in the earlier, intermediate, and later economies other than the parameters μ and γ^W.

There are 21 parameters total in the model. The frequency of the model is one quarter. Table 1.3 shows the steady state levels of key variables of the three economies. Table 1.4 lists the values of all parameters of the later economy, which are calibrated to target steady state values of the U.S. economy in 2007. Table 1.4 also shows the changes in parameter values in the earlier and intermediate economies.

	Variable	Earlier	Intermd	Later
A^W	wholesale bank assets	1.45	2.95	5.72
A^R	retail bank assets	4.24	4.95	6.97
A^W/K	**wholesale bank asset share**	**0.25**	**0.37**	**0.45**
ϕ^W	wholesale bank levearge	15.22	24.44	25.01
ϕ^R	retail bank leverage	4.96	7.73	15.06
	retail bank leverage without interbank loans	3.38	3.31	3.21
B	interbank loans	1.36	2.83	5.49
N^W	wholesale bank net worth	0.10	0.12	0.23
N^R	retail bank net worth	0.86	0.64	0.46
ϕ	aggregate bank leverage	4.56	6.66	10.42
R^W	wholesale bank return on assets	1.03	1.02	1.03
R^R	retail bank return on assets	1.03	1.02	1.01
K	capital (total assets)	4.34	5.07	7.20
Y	output	0.88	0.90	1.01
I	investment	0.11	0.13	0.18

Table 1.3: Steady States

For the calibration of the later economy, standard values in the literature are used for the household discount factor β, the capital share α, the depreciation rate δ, and the inverse labor supply elasticity φ. δ is set to be 0.025 to target the ratio I/K at 0.025. The values for the TFP process follow Nuño and Thomas (2017), who use linearly detrended Federal Reserve Bank of San Francisco-CSIP quarterly log TFP series. ρ_z and σ_z are chosen to match this series. $\bar{Z}$ is set so that the steady-state output is normalized to one. The values of ρ_σ are matched to the TFP series for all 4-digit SIC manufacturing industries constructed by the NBER and the U.S. Census Bureau, also following Nuño and Thomas (2017). σ_σ is used to match the volatility of leverage of the later eocnomy with its data counterpart.

Parameters σ, ψ, and χ^i (for i=W,R) are chosen to match the levels of wholesale and retail banking leverage. In particular, σ and ψ are used to target leverage in one banking sector whereas χ^W is set to target the difference in these two leverage

Parameter		Earlier	Intermd	Later
	Households and production			
β	discount rate	-	-	0.99
α	capital share	-	-	0.36
φ	inverse labor supply elasticity	-	-	1.0
δ	depreciation rate	-	-	0.025
ρ_z	autocorrelation, TFP	-	-	0.937
σ_z	standard deviation, TFP	-	-	0.0066
$\bar{Z}$	steady state TFP	-	-	0.496
	Firm technology			
ψ	mean of substandard technology	-	-	0.0001
η	variance of substandard technology	-	-	1.458
ρ_σ	autocorrelation, island-specific volatility	-	-	0.983
σ_σ	standard deviation, island-specific volatility	-	-	0.0032
σ	steady-state island-specific volatility	-	-	0.1063
	Wholesale banks			
γ^W	**management cost**	**0.0148**	**0.0148**	**0**
μ	**financing cost**	**0.0532**	**0**	**0**
θ^W	continuation rate	-	-	0.7
χ^W	incentive constraint	-	-	0.992
W^W	equity endowment for new banks	-	-	0.0098
	Retail banks			
γ^R	management cost	-	-	0.0148
θ^R	continuation rate	-	-	0.85
χ^R	incentive constraint	-	-	1.00
W^R	equity endowment for new banks	-	-	0.432

Table 1.4: Parameter Values

ratios. The leverage ratios are approximately 15 for the retail banking sector and 25 for the wholesale sector, roughly consistent with the empirical findings of the period around 2007 in Section 1.2. Similar numbers are also cited in Gertler and Kiyotaki (2010) for both banking sectors.

Parameters W^i are used to target an I/Y ratio of 18% for both stages of the economy. This means without any management cost the return on firm assets would be $(1-\delta)+\alpha Y/K = 1.025$. For parameters θ^i (for i = W,R), I assume that the retail banks have a higher continuation rate (85%) than the wholesale banks (70%) due to the regulations and insurance programs associated with the retail banking sector.

The parameter values for all economies satisfy the parameter assumptions introduced while solving the problem of the banks.

As Table 1.3 shows, the assets of wholesale banks are about 25% of total assets in the earlier economy and about 45% in the later economy. This is roughly consistent with the data as described in Section 1.2. The growth of the wholesale banking sector is driven by declines in the asset management cost parameter γ^W as well as the financing cost parameter μ. For the retail sector, γ^R is held constant across all four stages at 1.5%. For the wholesale sector, the cost of managing firm assets is assumed to be 1.5% in the earlier and intermediate economy, but is zero in the later economy. The later economy thus identifies the effect of γ^W, as γ^W dropping from 1.5% to 0% is the only difference in parameter values between the intermediate and later economies. As seen from Table 1.3, this change alone increases the share of wholesale bank assets from 37% to 45%. This decline in γ^W is intended to reflect the fact that there has been a series of innovations in financing technology for the wholesale banking sector relative to the retail banking sector over time that has improved the efficiency of intermediation through enhanced risk-sharing capacity, liquidity, and ease of monitoring.

The parameter μ is set to 0.05 in the earlier economy, to match the size of the wholesale banking sector in the data in the early 1980s, at about 25% of total assets. This cost drops to zero for the two subsequent economies. The intermediate economy identifies the effect of μ, as the change in μ is the only parameter change from the earlier eocnomy. As seen in Table 1.3, the decrease of μ from 0.05 to zero alone increases the share of wholesale bank assets from 25% to 37%. The change in μ is intended to capture the elimination of some banking regulations (for example the Gramm-Leach-Bliley Act in 1999 that repealed the 1933 Glass-Steagall Act) as well as the increasing ability of wholesale banks to circumvent regulations since the early 1980s.

To show more clearly the effects of a lower financing cost and improved management efficiency on the bank asset share in my model, Figure 1.13 below traces the steady state share of wholesale asset first as values of μ drop from their earlier value to zero (intermediate economy) and then as values of γ^W drop from their intermediate value to zero (later economy). As the figure shows, independently of the other parameter, a decrease of either parameter at any value corresponds to an increase of the steady state share of the wholesale sector. The vertical line in the figure represents the intermediate stage that separates the effects of the two factors. Eliminating the financing cost increases the wholesale sector's share of assets by 12

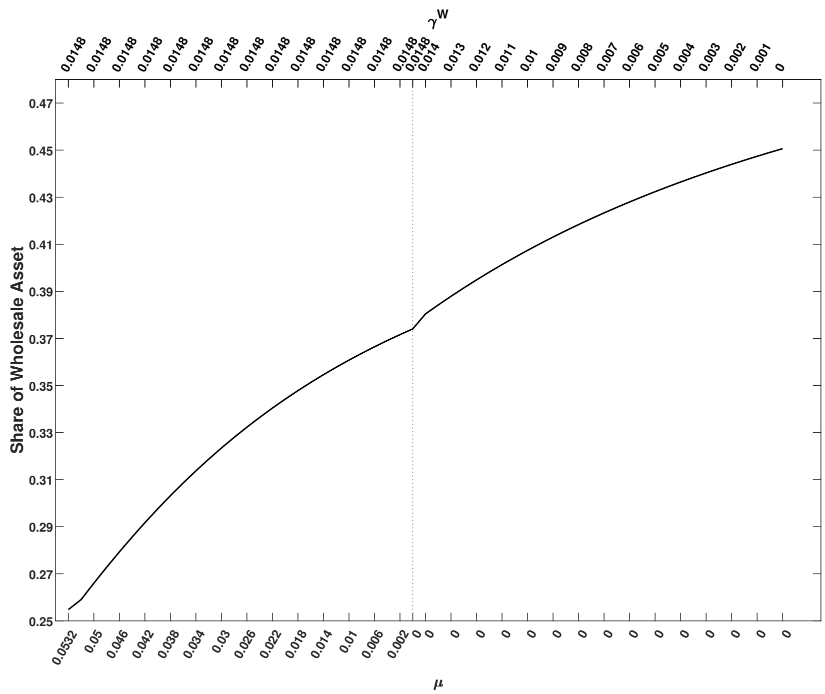

Figure 1.13: Growth of Wholesale Banking

percentage points, from about 25% to 37%. Complete elimination of asset management inefficiencies increases the wholesale share further by 8 percentage points (for an economy with no bank regulation), from about 37% to 45%.

Although the decrease of both the financing cost and management cost parameters increase the relative size of the wholesale sector, they do so through different mechanisms. The management cost affects wholesale banks' return on assets relative to that of the retail banks. As can be seen in Table 1.3, the asset return is the same for the two sectors regardless of the degree of financing cost (the earlier and the intermediate economy), whereas when the management cost parameter decreases, wholesale banks have an advantage in their return to asset (the later economy). Since the steady state value of assets for either sector is positively related to its asset return (see Section 1.4.1), this translates into a relative higher share of wholesale assets without affecting wholesale leverage.

The financing cost parameter, on the other hand, directly impacts the size of the bank balance sheet. When financing cost is high, bank net worth is reduced. This translates into a lower level of steady state assets (Section 1.4.1) as banks' balance sheets contract. In addition, a lower net worth increases the possibility of next period default and therefore the expected loss transferred to the creditors, which then triggers a tighter incentive constraint. This in turn leads to a lower level of leverage. In Table 1.3, when the financing cost is eliminated moving from the earlier to the intermediate economy, wholesale leverage rises from about 15 to 24, while it stays relatively stable from the intermediate to the later stage with the change of the management cost parameter.

In addition, the decrease of both the financing cost and management cost drastically increases the aggregate volume of interbank loans, as can be seen in Table 1.3. The observed increase of retail leverage is exclusively a result of the expanding interbank market: retail leverage without interbank loans (retail bank assets in firms divided by net worth) remains stable throughout the three stages of the economy. This is consistent with evidence described in Section 1.2.4 that the interbank loan amount has been rising since the early 1980s. As a percentage of total retail banking assets, interbank loans also grow significantly from about 32% in the earlier economy to about 79% in the later economy in the model. However, in the data (as shown in Section 1.2.4), this percentage grew only until around 2000 to about 45% before declining to about 38% in 2007. This could be due to the fact that the measurement of interbank loans is imperfect and is approximated by summing retail asset items that are most likely funding instruments of wholesale banks: repurchase agreements, short-term debt securities excluding government securities, and bank loans to non-depository financial institutions. This can be an underestimate, since some of the remaining asset categories of retail banks may also include interbank lending: for example, the categories of "loans nowhere else categorized" and "miscellaneous assets".

1.5.3 Responses to Shocks

I now examine the impact of each parameter change on how the aggregate economy responds to a change in asset return risk. In each economy, risk shocks to asset returns affect the leverage of wholesale banks more than retail banks due to a more strict incentive constraint. Therefore, the growth of wholesale banking implies a more volatile aggregate leverage and subsequently more volatile aggregate investment and output.

Figure 1.14 displays the responses to a one-standard-deviation increase in cross-sectional volatility for all three economies. Dotted lines represent the earlier economy, dashed lines the intermediate, and solid lines the later economy. [9]

As can be seen from the figure, a positive risk shock lowers bank leverage ratios for both sectors, but much more so for the wholesale sector compared to the retail sector. Lowered leverage ratios then lower bank asset levels, again more severely

[9] All models are solved with third-order perturbation. The reported responses of variables are percent deviations from steady state.

for the wholesale sector. A shrinking bank balance sheet for both sectors leads to subsequent drops of real aggregates: capital, investment and output all decrease upon impact. Corresponding to the drop in bank assets, interbank loans also drop as banks' balance sheets contract. Banks' net worth, on the other hand, increases slightly. This is because when the incentive constraint tightens with the presence of a risk shock, bank leverage has to decrease. Increasing equity and shedding assets are equivalent ways of keeping a lower leverage ratio.

In addition, all real aggregates are increasingly more responsive to a volatility shock as the wholesale sector grows. Since the only change from the earlier to the intermediate economy is the decreased financing cost, and the only change from the intermediate to the final economy is a decreased cost of management, this finding shows that both a lowered financing cost and improved efficiency of management of wholesale banks independently increase the responsiveness of the aggregate real economy by way of a bigger wholesale banking sector. Since a lower financing cost increases wholesale banks' leverage ratios, it can be argued that higher wholesale leverage can also be a factor that leads to a more volatile economy. While this could be the case, wholesale leverage remains stable when the management cost γ^W decreases, which means the difference in aggregate responses between the intermediate and the later economy show that an increased wholesale asset share alone leads to more responsive real aggregates, independent of increased leverage ratios.

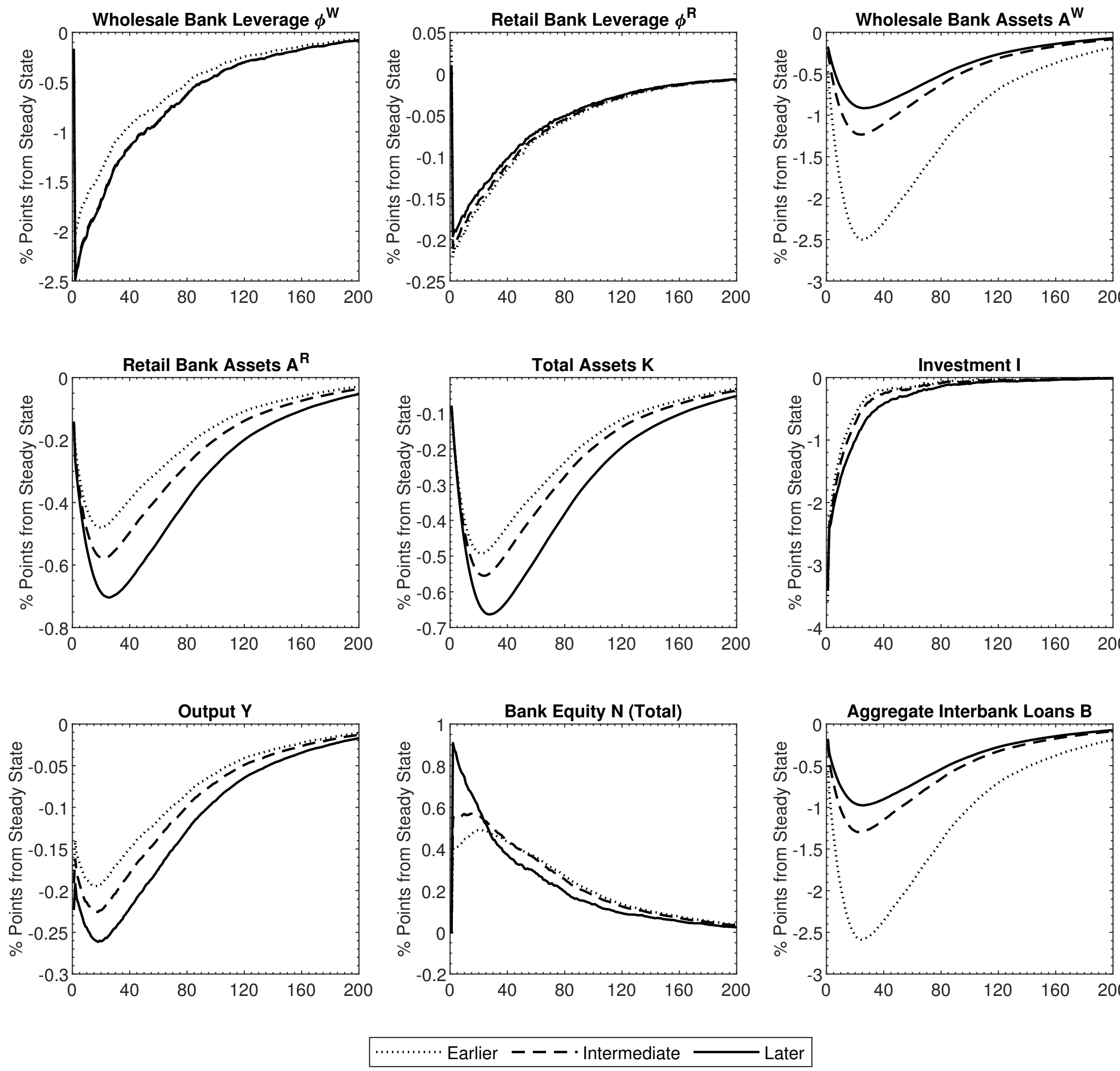

Figure 1.14: Impulse Responses to Risk Shock

Next, I explore the effects of a standard TFP shock on banking sectors and real aggregates, and compare these responses with the effects of a risk shock. Figure 1.15 plots the responses to the volatility shock and those to a one-standard-deviation fall in TFP (dotted line) for the later economy. The responses of the real aggregate variables are similar for both types of shocks: capital, investment, and output all go down. However, the TFP shock barely affects the banking aggregates. In particular, while leverage ratios drastically fall after a volatility shock, they barely change after a TFP shock. Intuitively, TFP shocks do not directly affect banks' incentives to invest inefficiently and thus have little effect on the leverage constraint imposed by investors.

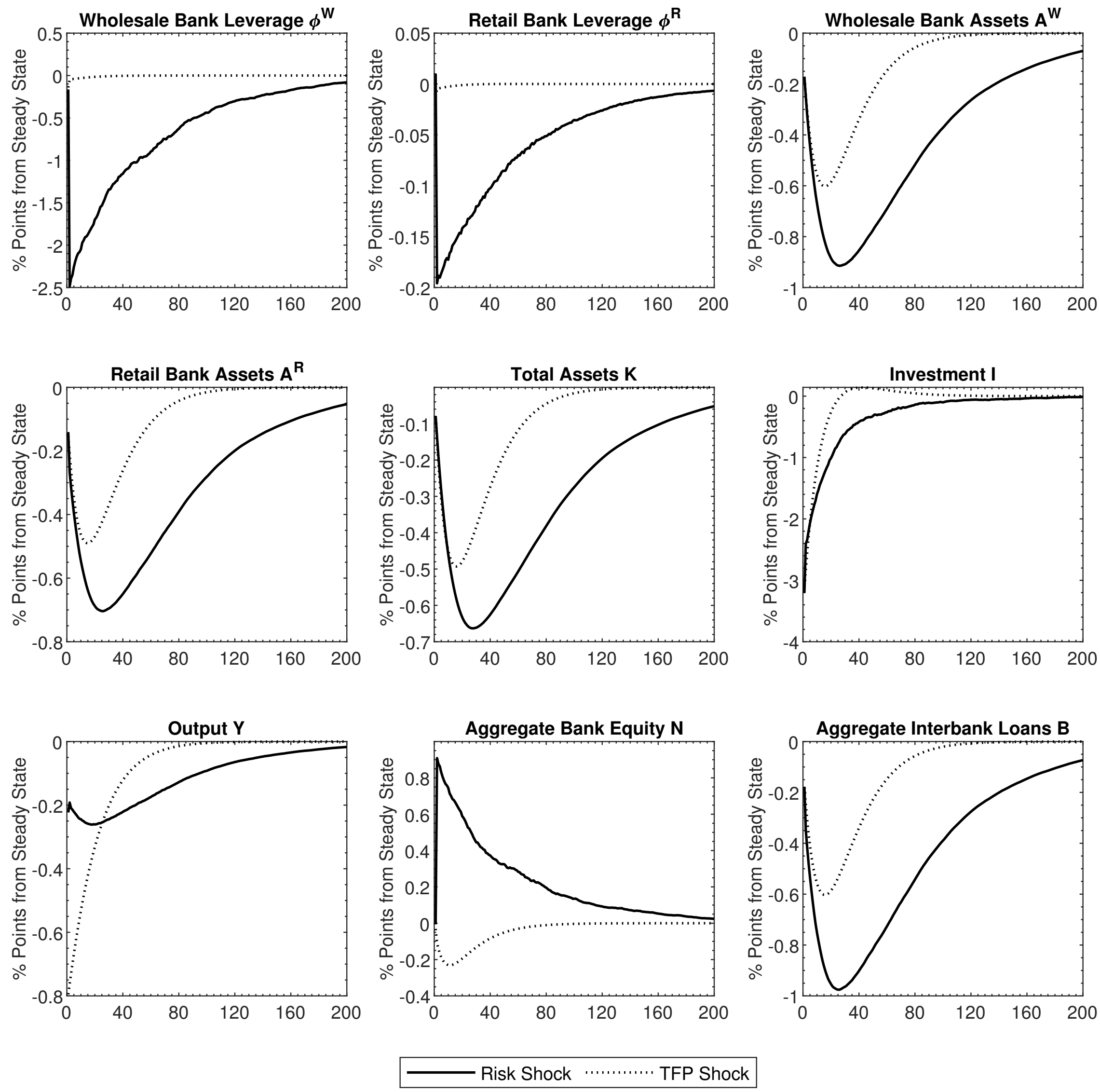

Figure 1.15: Impulse Responses: TFP and Risk Shocks

In Table 1.5 I also show the volatilities for key variables in response to each shock for all three economies (standard deviations %). Under a volatility shock, bank leverage and bank assets are more volatile for wholesale banks compared to retail banks in each economy, consistent with wholesale banks being more volatile due to tighter constraints. As a result, as the share of wholesale banks increases from the earlier to the later economy, the volatilities of aggregate leverage, capital, investment, and output all increase. By contract, the TFP shock alone does not generate any changes in the volatility of real aggregates as the wholesale sector grows. The TFP shock also induces very little change in the banking aggregates, for any of the economies.

	Risk Shock			TFP Shock			Both Shocks		
	Earlier	Interm	Later	Earlier	Interm	Later	Earlier	Interm	Later
ϕ^W	11.51	13.83	13.98	0.50	0.34	0.20	11.34	13.61	13.76
ϕ^R	9.77	9.23	9.53	1.72	2.31	2.55	9.78	9.44	9.77
A^W	20.86	9.75	7.46	5.88	4.16	3.23	21.25	10.54	8.08
A^R	3.75	4.48	5.74	2.45	2.49	2.56	4.40	5.15	6.26
K	3.89	4.31	5.41	2.52	2.53	2.58	4.54	5.02	5.98
Y	1.52	1.72	2.08	2.66	2.58	2.61	2.95	3.15	3.38
I	7.40	7.78	8.82	8.47	7.87	7.11	10.72	11.21	11.49
ϕ	8.30	8.83	9.90	1.30	1.74	1.53	8.27	8.91	9.87

Table 1.5: Volatilities of Stages of the Economy (Standard Deviations %)

Table 1.6 presents the co-movements (correlations) of assets, investment, and output with bank leverage for all economies. Under a volatility shock, leverage of the wholesale banks, of retail banks, as well as of the total banking sector, all are positively correlated with assets, investment, and output. This illustrates that bank leverage is procyclical for both sectors. The correlations are consistently high, with those for wholesale leverage generally higher than those for retail leverage. Under a TFP shock, bank balance sheets are also procyclical, but the co-movements are much weaker than under a risk shock.

		Risk Shock			TFP Shock			Both Shocks		
Correlation		Earlier	Interm	Later	Earlier	Interm	Later	Earlier	Interm	Later
ϕ^W	A^W	0.9143	0.9194	0.9009	0.6993	0.6979	0.5671	0.8873	0.8458	0.8196
	K	0.926	0.9145	0.8873	0.7149	0.689	0.5406	0.8016	0.7863	0.7914
	Y	0.969	0.9606	0.9503	0.9207	0.9199	0.8697	0.538	0.5508	0.5976
	I	0.7662	0.7867	0.8573	0.803	0.8369	0.8896	0.5681	0.5777	0.682
ϕ^R	A^R	0.8968	0.9146	0.8945	0.7605	0.7379	0.5213	0.7816	0.8004	0.8094
	K	0.8813	0.8981	0.8742	0.7177	0.6969	0.4745	0.7675	0.7749	0.7804
	Y	0.9067	0.9355	0.9283	0.9212	0.9214	0.8481	0.5289	0.546	0.5911
	I	0.6473	0.7307	0.8055	0.8006	0.8307	0.9137	0.4969	0.5419	0.6449
ϕ	K	0.9967	0.9906	0.9652	0.9728	0.9865	0.9941	0.916	0.9324	0.9212
	Y	0.9874	0.9923	0.9904	0.807	0.8044	0.7894	0.612	0.6747	0.7045
	I	0.5703	0.6453	0.7744	0.2903	0.3031	0.3673	0.4279	0.4933	0.6358

Table 1.6: Co-movements with Leverage

1.6 Economies from the Early 1980s to the Late 2000s

The earlier and intermediate economies in the previous analyses do not produce realistic steady state values, especially their leverage ratios and values of real aggregates, since the only parameters different from the later economy (fully calibrated to the steady state of the U.S. economy in 2007) are those governing the size of the wholesale sector. In the following set of analyses I calibrate an earlier economy that corresponds to the steady state of the U.S. economy in the early 1980s, and compare this earlier stage with the later stage of the U.S. economy in the late 2000s.

1.6.1 Calibration and Steady State

As before, the two economies are calibrated to reflect the observed growth of the wholesale banking sector from the early 1980s to 2007. But now I change additional parameters to calibrate the two economies to both have a normalized output value of one, an I/K ratio of 0.025, as well as bank leverage ratios that are consistent with values in the data for these two points in time. Table 1.7 below shows the steady state levels of relevant variables of the two economies. Table 1.8 lists the parameter values and highlights any differences between the two economies.

Specifically, σ and χ^W are changed in the earlier economy to match the levels of wholesale and retail banking leverage. The leverage ratios for the retail banking sector are approximately 15 in both earlier and later economies, while for the wholesale sector they are 25 and 15 for the later and earlier economies, respectively. I keep the leverage ratio of the retail banking sector constant between the earlier and the later economies as the change in the leverage ratio over this period of time is mild for the retail sector in the data, and a ratio of 15 is close to the average across this time period for depository institutions (see Figure 1.7). The leverage ratio for the wholesale banking sector is set to roughly 15 in the earlier economy and 25 in the later economy. This is roughly consistent with the empirical findings of Section 1.2. For the later economy in particular, similar numbers are also cited in Gertler and Kiyotaki (2010) [34] for both banking sectors. Parameters W^W and $\bar{Z}$ are also changed to target an I/Y ratio of 18% as well as to normalize output to one for both stages of the economy. This means that without any management costs the return on firm assets would be $(1-\delta)+\alpha Y/K = 1.025$. This is reflected by the steady state returns on assets for both banking sectors: the two sectors have the same level of returns in the earlier economy, while in the later stage, the wholesale banks have higher returns, consistent with the rising management cost advantage for the wholesale sector over time.

The parameter values for both economies satisfy the parameter assumptions introduced while solving the problem of the banks.

	Variable	Earlier	Later
A^W	wholesale bank assets	2.34	5.72
A^R	retail bank assets	7.04	6.97
A^W/K	**wholesale bank asset share**	**0.25**	**0.45**
K	capital (total assets)	7.20	7.20
Y	output	1.00	1.00
I	investment	0.18	0.18
ϕ^W	wholesale bank levearge	15.07	25.01
ϕ^R	retail bank leverage	15.02	15.06
ϕ	aggregate bank leverage	11.53	10.42
R^W	wholesale bank return on assets	1.01	1.03
R^R	retail bank return on assets	1.01	1.01

Table 1.7: Steady States

Parameter		Earlier	Later
	Households and production		
β	discount rate	0.99	0.99
α	capital share	0.36	0.36
φ	inverse labor supply elasticity	1.0	1.0
δ	depreciation rate	0.025	0.025
ρ_z	autocorrelation, TFP	0.937	0.937
σ_z	standard deviation, TFP	0.0066	0.0066
$\bar{Z}$	**steady state TFP**	**0.444**	**0.494**
	Firm technology		
ψ	mean of substandard technology	0.0001	0.0001
η	variance of substandard technology	1.458	1.458
ρ_σ	autocorrelation, island-specific volatility	0.983	0.983
σ_σ	standard deviation, island-specific volatility	0.0032	0.0032
σ	**steady-state island-specific volatility**	**0.0327**	**0.1063**
	Wholesale banks		
γ^W	**management cost**	**0.0148**	**0**
μ	**interbank regulation**	**0.02**	**0**
θ^W	continuation rate	0.70	0.70
χ^W	**incentive constraint**	**0.999**	**0.992**
W^W	**equity endowment for new banks**	**0.144**	**0.0098**
	Retail banks		
γ^R	management cost	0.0148	0.0148
θ^R	continuation rate	0.85	0.85
χ^R	incentive constraint	1.00	1.00
W^R	equity endowment for new banks	0.432	0.432

Table 1.8: Parameter Values

1.6.2 Responses to Shocks

Next I compare how the economy in the early 1980s and the economy in the late 2000s respond differently to a change in asset return risks.

Figure 1.16 displays the responses to a one-standard-deviation increase in cross-sectional volatility for both the later (solid line) and the earlier (dotted line) economies.

Similar to the previous exercises, all the real aggregates are more responsive to a volatility shock in the later economy compared to the earlier economy. Both economies exhibit a drop in investment, total assets, and output, but the drop is much more significant for the later economy when the wholesale banking sector is significantly larger. Consistent with a more severe leverage constraint in the presence of a risk shock, the wholesale sector displays a more responsive bank leverage as well as more volatile bank assets compared with the retail sector. Interbank loans also decrease as banks deleverage, while net worth slightly rises, similar to previous analyses.

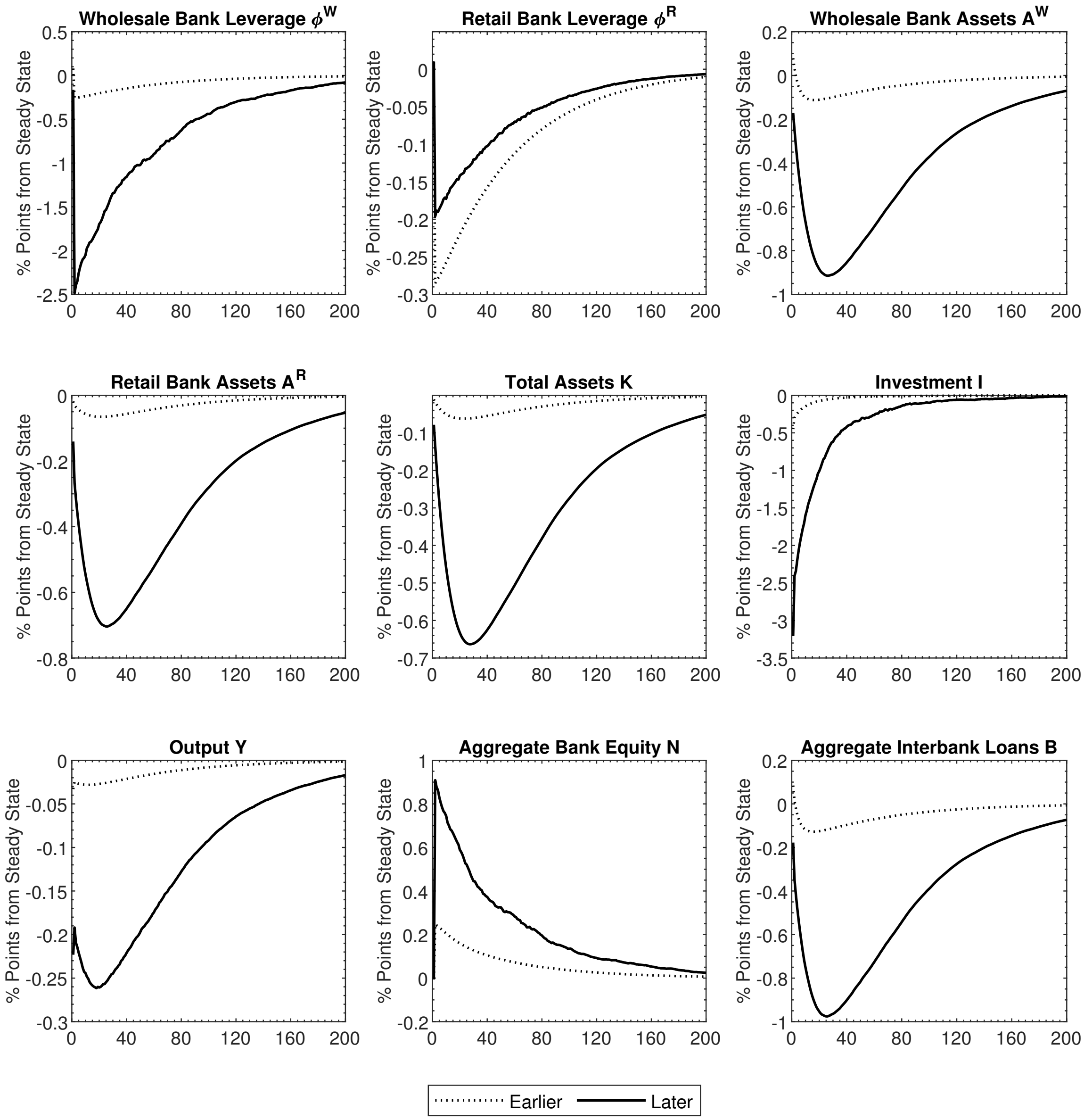

Figure 1.16: Impulse Responses to Risk Shock

For comparison, I also show in Figure 1.17 the response of both the later and the earlier economies to a negative TFP shock. Overall, there is very little difference between the two sets of responses, especially in terms of aggregate capital, investment, and output. Although the TFP shock does seem to cause more reaction in the banking aggregates in the later economy, the difference is very small compared to the differences under a volatility shock (Figure 1.17).

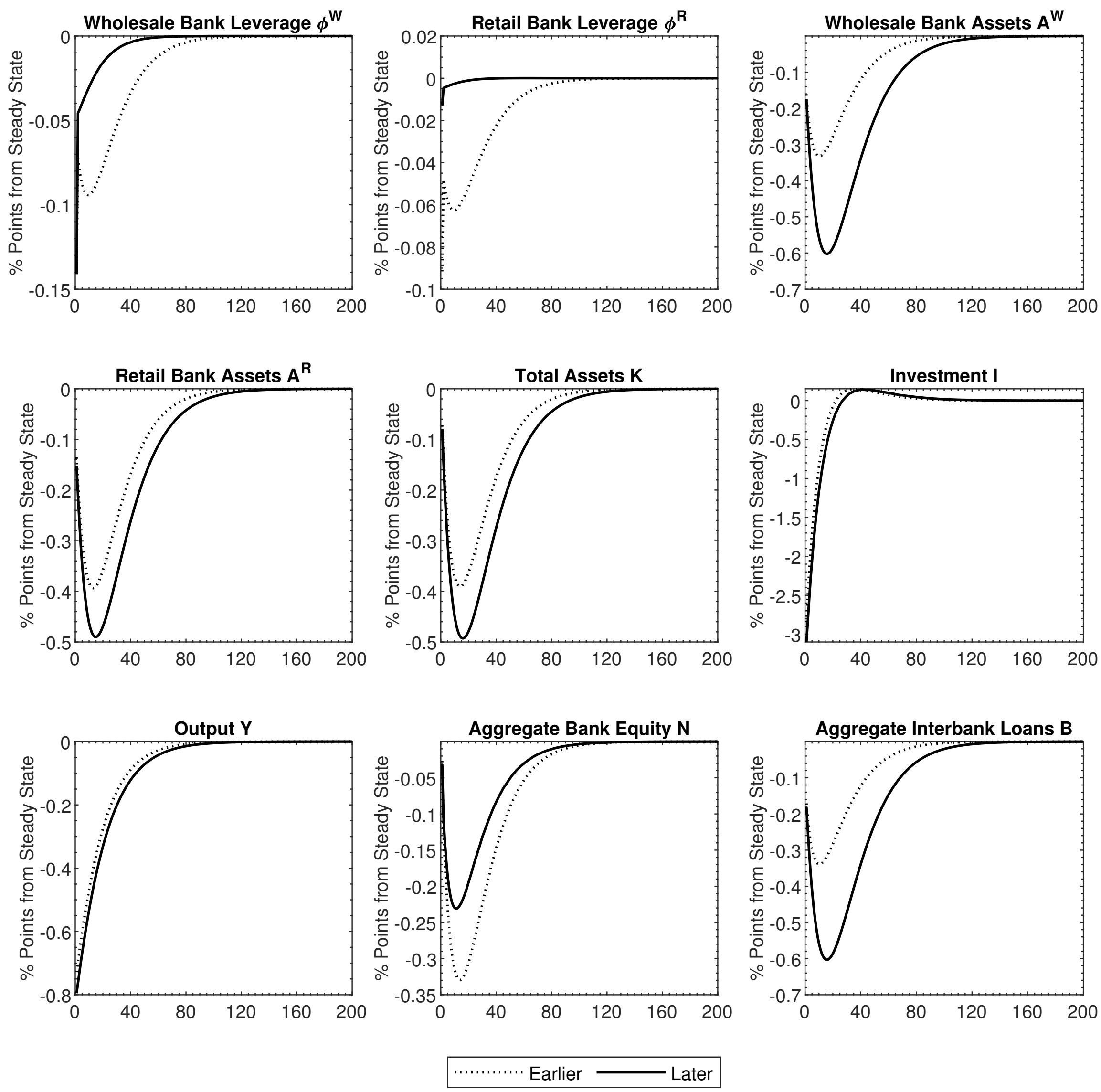

Figure 1.17: Impulse Responses to TFP Shock

Table 1.9 below displays the volatilities for key variables in response to each shock for both the earlier and the later economies (standard deviations %) in comparison with the data. With the volatility shock present, the volatilities of bank leverage, investment, capital and output are all much higher in the later economy compared to the earlier economy. In addition, the volatility of the wholesale sector is higher than that of the retail sector for each eocnomy, consistent with wholesale banks being more volatile due to tighter constraints. The TFP shock alone does not generate the same differences between the two sectors, nor does it generate as much difference between the two economies.

The empirical counterparts in Table 1.9 are obtained from Flow of Funds. These standard deviations are obtained for a four year window from 1983Q3 to 1987Q2 for the earlier economy and from 2006Q3 to 2010Q2 for the later economy.[10] The time windows were chosen so that they reflect the consequences of whatever shocks the economy actually experienced starting from possible states of the two economies calibrated in the model (the early 1980s and before the crisis). For example, the later period includes the crisis period, reflecting the actual volatilities as a result of the shocks hitting the economy around the eve of the financial crisis. Almost all variables are more volatile in the later period, indicating a closer resemblance with the economy with a high share of wholesale banking subject to risk shocks.[11]

[10] All model numbers come from a third-order perturbation, as percent deviations from steady state. The data are log-detrended within each four year period.

[11] Note it is not my goal to match the model exactly with the data, as the data reflect volatilities resulting from actualized shocks in history whereas the model results reflect isolated, specifically quantified shocks in theory. In addition, data on leverage is not available for all sub-sectors as noted in Section 1.2.

	Risk Shock		TFP Shock		Both Shocks		Data	
	Earlier	Later	Earlier	Later	Earlier	Later	Earlier	Later
ϕ^W	1.47	13.98	0.47	0.20	1.54	13.76	5.91	14.00
ϕ^R	1.75	9.53	0.21	2.55	1.74	9.77	5.02	3.70
A^W	0.75	7.46	1.58	3.23	1.79	8.08	2.55	13.41
A^R	0.48	5.74	1.94	2.56	2.04	6.26	1.15	2.92
K	0.45	5.41	1.92	2.58	2.02	5.98	1.31	3.65
Y	0.20	2.08	2.29	2.61	2.33	3.38	0.78	1.27
I	0.86	8.82	5.90	7.11	5.98	11.49	5.12	7.31
ϕ	1.59	9.90	0.32	1.53	1.61	9.87	4.37	18.84

Table 1.9: Volatilities of Earlier and Later Economy (Standard Deviations %)

Table 1.10 presents the correlations of assets, investment, and output with bank leverages for the earlier and the later economies as well as from the data. Under a volatility shock, in the model as in the data, leverage of the wholesale and retail banking sectors, as well as of the total banking sector, all are positively correlated with assets, investment, and output. Also, under a risk shock, wholesale bank leverage is more correlated with aggregate investment in the later economy than in the earlier economy, and a more sizable wholesale sector is associated with aggregate bank leverage being more procyclical (higher correlations between aggregate bank leverage and capital, investment, and output) in the later economy compared with the earlier economy. These observations are consistent with the data. Under a TFP shock, the correlations are in general lower than those generated by a risk shock. TFP shocks also does not produce the differences between the two sectors or between the two time periods as observed in the data. The data thus resemble responses to a volatility shock more than a TFP shock.

This is evidence that as the financial system evolves into one with a more dominant wholesale sector, movements in banking aggregates, specifically bank leverage ratios, have an increasingly stronger impact on the real economy when there are fluctuations in asset return risk.

		Risk Shock		TFP Shock		Both Shocks		Data	
Correlation		Earlier	Later	Earlier	Later	Earlier	Later	Earlier	Later
ϕ^W	A^W	0.9342	0.9009	0.9801	0.5671	0.6597	0.8196	0.6353	0.8784
	K	0.9449	0.8873	0.9485	0.5406	0.5006	0.7914	0.7893	0.9225
	Y	0.9684	0.9503	0.9420	0.8697	0.3892	0.5976	0.4876	0.8762
	I	0.6875	0.8573	0.6123	0.8896	0.2992	0.6820	0.3635	0.7077
ϕ^R	A^R	0.9671	0.9990	0.7027	0.9882	0.3240	0.9848	0.7252	0.7886
	K	0.9537	0.9951	0.6580	0.9935	0.3061	0.9771	0.6866	0.8852
	Y	0.9821	0.9896	0.9610	0.7702	0.2223	0.7537	0.6437	0.4318
	I	0.7095	0.6830	0.9244	0.3379	0.2329	0.5688	0.5002	0.2134
ϕ	K	0.9479	0.9652	0.9202	0.9941	0.4016	0.9212	0.7669	0.9416
	Y	0.9804	0.9904	0.9642	0.7894	0.2952	0.7045	0.6114	0.8570
	I	0.7207	0.7744	0.6757	0.3673	0.2541	0.6358	0.4699	0.6774

Table 1.10: Co-movements with Leverage

1.7 Conclusion

The wholesale banking sector is distinct from the traditional retail banking sector in various aspects, including balance sheet structure and the sophistication of their investors. Due to a series of financial innovations as well as regulatory changes, wholesale banking experienced drastic growth since the 1980s and became prominent by the eve of the financial crisis. I document this evolution of the wholesale banking sector compared to the retail banking sector and highlight their differences. In my model, I show that the growth of wholesale banking can be explained by a decrease in intermediation costs along with a lessened level of interbank regulation in a framework that distinctly models the two different types of banks. In addition, this growth has lead to a stronger link between the financial and the real sectors of the economy, and consequently a more volatile aggregate economy, especially when there are risk shocks present.

Chapter 2: Uncertainty and the Macroeconomy: the Role of Bank Leverage

2.1 Background

2.1.1 Uncertainty and the Macro-economy

Uncertainty shocks have been the focus of a recent, growing strand of macroeconomic literature. Uncertainty can have important impacts on the economy because it influences agents' current decisions. The concept of uncertainty can be broad and amorphous. Thus there is no perfect measure of uncertainty but instead a range of proxies. Existing research has primarily relied on measures of time-series volatility and cross-section dispersion as proxies of uncertainty. For example, the volatility of the stock market or GDP forecasts is often used as a measure of uncertainty, since when a data series becomes more volatile, it is harder to predict (Bloom, 2014 [21]).

Since the Great Recession, shocks to uncertainty have been increasingly recognized as an important source of aggregate fluctuations. For example, Stock and Watson (2012) [47] conclude that "the main contributions to the decline in output and employment during the (2007-2009) recession are estimated to come from financial and uncertainty shocks", while the Fed and the ECB have since built uncertainty shocks into their core models as a main driver of business cycles. In addition, there is growing empirical evidence of the aggregate effects of shocks to uncertainty. For instance, Bloom (2014) [21] observes that almost every macroeconomic indicator of uncertainty appears to be countercyclical, and that micro uncertainty proxies also appear to rise sharply in recessions and fall in booms. Basu and Bundick (2017) [16] find that identified uncertainty shocks in the data cause significant declines in output, consumption, investment, and hours worked.

Different theories regarding the channels through which uncertainty may impact the real economy have been proposed in the literature. The real options channel considers how uncertainty can delay firms' decisions to invest and hire within a framework of irreversible investment (Bernanke, 1983 [17]; Bertola and Caballero, 1994 [18]; Abel and Eberly, 1994, 1996 [1, 2]; Caballero and Pindyck, 1996 [25]; Bloom, 2009 [20]; Bloom et al., 2018 [22]; Bachmann and Bayer, 2009, 2013 [13] [14]). Since the Great Recession, an emergent literature has pointed to financial market frictions as an additional channel through which volatility fluctuations can affect macroeconomic outcomes (Arellano et al., 2019 [12]; Christiano et al., 2014 [27]). Heightened uncertainty can affect the risk attitudes of investors and lead to increased risk premia. To the extent that external finance is subject to agency problems, an increase in uncertainty will raise the cost of finance, inducing a decline in investment spending and growth. Other mechanisms explored in the literature include the growth opportunity channel, the Oi-Hartman-Abel-Caballero channel, and the learning by doing channel, all of which also focus on firms' investment decisions, as well as the precautionary saving channel, which focuses on household consumption responses to perceived uncertainty.[1] In this chapter I explore the potential role of financial intermediaries in channeling aggregate uncertainty shocks to the real economy, specifically the role of bank leverage ratios.

2.1.2 Role of Financial Intermediaries and Bank Leverage

The relatively limited literature exploring financial friction channels of aggregate uncertainty largely focuses on the behavior of firms (Gilchrist et al., 2014 [35]; Bloom et al., 2007 [19]; Bloom et al., 2018 [22]), while the role of financial intermediaries has been mostly overlooked. In particular, the potentially important role of bank leverage in the transmission of the effect of uncertainty has not been well documented.

Bank leverage refers to the ratio of total bank assets (lending) to bank equity (net worth). The behavior of bank leverage is important in its own right and is the focus of some recent contributions in the macroeconomic literature. Higher bank leverage allows banks to lend more for a given level of net worth. Fluctuations of bank leverage thus lead to fluctuations in bank lending activities and the supply of bank credit, which subsequently affects aggregate investment and real economic

[1] The learning-by-doing channel assumes that firms have imperfect information about the underlying state of the eocnomy, and learn about the true state only by a sequence of investments. Thus in a high uncertainty environment firms conduct more intensive investment to learn the true state (e.g. Pavlova 2002 [45]). The precautionary savings channel proposes that uncertainty lowers economic activities because consumers increase their precautionary savings when they perceive more risk in the eocnomy (e.g. Leduc and Liu 2012 [43]). The other two of these channels associate higher uncertainty with positive real outcomes: The growth options insight argues that uncertainty can encourage investment if it increases the size of the potential prize, while the Oi-Hartman-Abel-Caballero channel postulates that firms may be risk loving if they can exploit good opportunities associated with higher volatilities, leading to increased investments.

activity.

The importance of fluctuations in bank leverage has recently entered the spotlight as a result of the Great Recession. A particularly influential strand of literature has focused on the crucial role played by the deleveraging of the financial intermediation sector in the unraveling of the crisis (Brunnermeier, 2009 [23]; Gorton and Metrick, 2010, 2012 [36, 37]). Adrian and Shin (2009) [3] observe that "financial crises tend to be preceded by marked increases of leverage." At the same time, research has also documented that bank leverage exhibits important cyclical behaviors in normal times that are associated with fluctuations of bank credit and aggregate activity. For example, Adrian and Shin (2010a, 2011) [4, 7] document positive correlations between bank leverage growth and bank credit growth. Adrian, Moench and Shin (2013) [9] establish that the procyclicality of credit supply is a consequence of how financial intermediaries manage their leverage in reaction to changing economic conditions.

The exact factors that lead to fluctuations of bank leverage are still not well understood in the empirical literature. However, various theoretical models have been proposed linking the cyclicality of bank leverage with changes in uncertainty (Ashcraft, Gârleanu, and Pedersen, 2011 [11]; Brunnermeier and Pedersen, 2009 [24]; Dang, Gorton, and Holmström, 2010 [29]; Geanakoplos, 2010 [31]; and Gorton and Ordoñez, 2014 [38]). Adrian and Shin (2010c, 2011) [6, 7] discuss how financial intermediates actively manage their leverage ratios based on risk management policies and that the cycliliality of bank leverage is a consequence of active management of risk.[2] Adrian and Shin (2014) [10] postulate a model in which financial intermediaries adjust their leverage levels following a value-at-risk (VaR, a measure of financial market risk) rule of balance sheet management, in which financial intermediaries react to a spike in risk by sharply reducing leverage to maintain a stable VaR/equity ratio.

Given the well documented cyclicality of bank leverage as well as existing theories linking it to uncertainty, it is worthwhile to investigate empirically whether changes in aggregate uncertainty have predictive power over changes in bank leverage ratios, and subsequently aggregate bank credit supply and the real economy.

2.1.3 Difference between Wholesale and Retail Banks

Over the last forty years, the U.S. financial system has undergone a major transformation, transitioning from a primarily bank-based financial system to one based on market-based intermediaries with the growth of the wholesale banking sector. It has been documented that the wholesale banking sector has grown drastically and overtaken traditional banking since the early 1980s (Gertler, Kiyotaki, and Prestipino, 2016 [34]). Wholesale banks are based on capital market financing rather than traditional intermediation between depositors and ultimate borrowers. Compared to traditional retail banking, they tend to be highly leveraged, often with short term debt, and tend to borrow heavily from other financial institutions in the interbank market (wholesale market) as opposed to the traditional retail market for

[2] Risk is a concept closely related to, if not equivalent to, the concept of uncertainty. They are usually measured in similar ways, as the volatility or dispersion of financial or real indicators.

household deposits.

Given their short-term borrowing through commercial paper and repurchase agreements, wholesale intermediaries are much more sensitive to capital market conditions and therefore reflect a purer signal of marginal funding conditions (Adrian and Shin, 2010b [5]). Additionally, retail banking sectors are often subject to heavier regulation and monitoring, which can be another reason for their limited reactions to market fluctuations compared to their wholesale banking counterparts. These differences imply that the wholesale banking sector is potentially more volatile than the retail banking sector. Gertler, Kiyotaki, and Prestipino (2016) [34] emphasize that the epicenter of the recent financial crisis featured malfunctioning of the wholesale banking sector, with dry-ups and bank runs, while the retail markets remained relatively stable. Adrian and Shin (2010b) [5] find that broker-dealer assets (a main sub-sector of wholesale banking) are more informative than commercial bank assets in predicting GDP.

Specifically relevant to the present paper, the leverage ratios for the two types of banks behave very differently, in a way that is consistent with a more reactive and volatile wholesale sector. For example, leverage grew drastically for the wholesale banking sector preceding the Great Recession while retail banking leverage remained relatively steady (see Chapter 1). More generally, wholesale and retail bank leverage exhibit different cyclical behavior. Nuno and Thomas (2017) [44] observe much higher volatility and procyclicality of leverage for broker-deals than for commercial banks (where procyclicality can refer to the correlation between bank leverage and bank assets or between bank leverage and real GDP). If the two types of banks react differently to market conditions by managing their leverage ratios differently, then this will affect aggregate fluctuations in assets and credit supply.

Given the more volatile nature of the wholesale banking sector and its characteristic sensitivity to market conditions, it naturally follows that when aggregate uncertainty is elevated, wholesale banks may respond more strongly than their retail counterparts, likely through more active changes in bank leverage ratios. This, combined with the increased influence of the wholesale sector in the financial system, may constitute an important channel for financial market fluctuations to propagate to the rest of the economy.

2.1.4 Contribution and Relation to Literature

This study investigates empirically the roles the traditional retail banking sector and the wholesale banking sector play in the transmission of shocks to aggregate uncertainty. More specifically, I focus on differences in how leverage responds to uncertainty shocks between the two banking sectors. As changes in uncertainty induce fluctuations in bank leverage, bank credit fluctuates, leading to changes in aggregate spending and output.

This study contributes to the empirical literature on the impact of uncertainty on the aggregate economy. This growing body of research has considered multiple channels, but channels involving financial intermediaries have not been well explored. This study is also closely related to the empirical literature focusing on how the balance sheet behavior of financial intermediaries is related to real economic outcomes. However, the existing literature typically focuses on bank credit rather than bank leverage; it also pays more attention to financial crisis rather than cyclical fluctuations in general (Schularick and Taylor, 2012; Jordà et al., 2013). Thus I contribute to the literature by studying the link between fluctuations in aggregate uncertainty and bank leverage and how this link has an impact on the real economy during both normal and crisis periods. Importantly, I also document this linkage separately for retail and wholesale banking, as these two sectors react differently to uncertainty, and therefore impact the real economy in distinct manners and with different magnitudes.

2.2 Measurements

2.2.1 Data

Measure of Uncertainty:

For this paper I use a standard proxy for aggregate uncertainty in the literature: financial market volatility as measured by VXO. The VIX and VXO are compiled by the Chicago Board Options Exchange (CBOE) and measure the 30-day expected volatility of the U.S. stock market as implied by S&P500 (S&P100 for VXO) index options. Both series are obtained from the CBOE. I choose the VXO since it dates back to 1986, whereas the VIX only has data since 1990.

Measures of Bank Balance Sheets:

I obtain quarterly data from the U.S. Flow of Funds from the Federal Reserve on bank assets and equity for all sub-sectors of banking with available data. Bank sub-sectors are categorized as part of either the retail or wholesale banking sector based on their main source of funding instruments. Bank leverage ratios are obtained by dividing bank assets by bank equity.

Measures of Real Economic Activity:

I focus on real investment and output to analyze fluctuations in the aggregate real economy. Real investment, real GDP, and the GDP deflator are obtained from the Bureau of Economic Analysis.

Other Data Series:

The Federal Funds Rate and PCE core inflation are taken from Federal Reserve Economic Data (FRED). Moody's yield on Baa-rated corporate bonds and yields on Treasury securities are taken from the FRED-QD dataset, which takes quarterly averages of higher frequency series from FRED.

The horizon for the analyses in this paper is from 1986 to 2019 (the longest period available for VXO data) and the frequency is quarterly (the highest frequency available from the Flow of Funds).

2.2.2 Categories of Banking Sub-sectors

Financial intermediaries are categorized into retail or wholesale sectors based on their main source of funding/liabilities. Instruments that are supplied by financial intermediaries and demanded by households are considered retail funding, while instruments that are mainly traded among financial intermediaries are considered wholesale funding. Table 2.1 lists the specific instruments falling into each category.

This categorization roughly follows that used in Gertler, Kiyotaki, and Prestipino (2016) [34].

Retail Funding	Checkable deposits and currency Time and saving deposits Money market mutual fund shares Mutual fund shares
Wholesale Funding	Security repurchase agreements Financial open market paper Agency/GSE backed securities Financial corporate bonds Retail loans to wholesale

Table 2.1: Classification of Funding Instruments

Based on this classification, intermediaries are categorized into retail or wholesale banking as in Table 2.2. The third column of Table 2.2 shows the percent distribution of total assets within retail and wholesale sectors for the first quarter of 2007, on the eve of the financial crisis.

		Size	Asset	Equity
Retail Banking Sector	Private Depository Institutions	63.4%	Yes	Yes
	Mutual Funds	23.9%	Yes	-
	Money Market Mutual Funds	12.8%	Yes	-
Wholesale Banking Sector	Security Broker-Dealers	21.1%	Yes	Yes
	ABS Issuers	20.6%	Yes	-
	GSE Mortgage Pools	19.1%	Yes	-
	Government Sponsored Enterprises	13.3%	Yes	Yes
	Finance Companies	9.6%	Yes	Yes
	Holding Companies	8.1%	Yes	Yes
	Funding Corporations	6.5%	Yes	-
	Real Estate Investment Trusts	1.6%	Yes	Yes

Table 2.2: Categorization of Banking Sectors and Data Availability

Data on total assets are available for all of the subsectors listed above from the Flow of Funds. For the calculation of leverage ratios, I divide total assets by "equity capital". Data on equity capital are available during the period analyzed for only five sub-sectors: U.S. charted depository institutions, security broker-dealers, finance companies, government sponsored enterprises, and holding companies. U.S. chartered depository institutions are the main sector within private depository institutions, holding about 84% of all assets of private depository institutions and 53% of the assets of the entire retail banking sector at the beginning of 2007. Security broker-dealers, finance companies, government sponsored enterprises and holding companies together make up more than half of the total assets of the wholesale banking sector in the first quarter of 2007. In subsequent analyses of bank leverage ratios, only sub-sectors with available data are included.

All data series are deflated by the GDP Implicit Price Deflator. Data are also adjusted for discontinuities in the Flow of Funds data construction.[3]

[3]Data on levels (series identifier 'FL') from the Flow of Funds suffer from discontinuities that are caused by changes in the definition of the series. The Flow of Funds constructs discontinuities series (series identifier 'FD') to correct for such changes. Specifically, each series of the flow data (series identifier 'FU') is equal to the change in level outstanding less any discontinuity: $FU_t = FL_t - FL_{t-1} - FD_t$. Therefore, the flow data are free from such discontinuities. In order to adjust for discontinuities in the level series, the value of the level in the first period of the sample is used and the flows data are accumulated onwards to obtain level data for subsequent periods.

2.3 Impact of Macro-uncertainty Shocks

In this section, I use VARs to evaluate the impact of uncertainty shocks on the financial sector and real economic outcomes. I identify an uncertainty shock using a Cholesky decomposition in a VAR model including balance sheet variables for both retail and wholesale banking sectors. The benchmark VAR model is ordered as follows: VXO, retail bank leverage, wholesale bank leverage, retail bank assets, wholesale bank assets, investment, output, the PCE deflator, the credit spread, and the Federal Funds Rate (a measure of monetary policy). This ordering assumes that uncertainty shocks can have an immediate impact on the financial sector and then the real economy, but non-uncertainty shocks do not affect the implied stock market volatility on impact. Since the VXO data start in 1986, the VAR is estimated using quarterly data over the period of 1986 - 2019 with four lags. Other than the credit spread and the effective federal funds rate, all variables enter the VAR in log levels.

Figure 2.1 shows the dynamic responses of both banking sectors and the aggregate real economy to a positive shock to the VXO along with 95% confidence intervals computed with 2000 Monte Carlo simulations. A one-standard-deviation shock to aggregate uncertainty leads to a significant and protracted reduction of both leverage and assets for the wholesale banking sector, but not so for the retail banking sector. The shock then triggers statistically significant declines in aggregate investment and output that bottom out around one year after the shock. The economic decline leads to a decrease in the price level that lasts for about two years, which elicits an easing of monetary policy, as evidenced by the drop in the federal funds rate. The credit spread spikes after the shock, signalizing heightened stress in the financial system, and takes about two years to go back to its long run level.

These results are evidence that financial institutions indeed constitute a channel for the effect of aggregate uncertainty shocks on the real economy. Importantly, wholesale bank leverage displays positive co-movement with bank assets and plays a key role in changes on wholesale bank balance sheets following uncertainty shocks. Furthermore, in response to shocks to macro-uncertainty, wholesale bank leverage exhibits positive co-movement with real aggregates. This can be seen as evidence that when market uncertainty rises, wholesale banks exert more stringent limits on their leverage ratios to reduce risk exposures associated with a more volatile environment, which in turn reduces their total lending. This lowers aggregate credit supply and subsequently aggregate real activity.

Unlike the wholesale banking sector, an uncertainty shock does not induce statistically significant responses of retail bank leverage ratios, while retail bank assets actually go up, moving in the opposite direction as the real economy. This increase in retail bank assets is also of much lower magnitude than the decline of wholesale bank assets. This is consistent with the notion that the wholesale banking sector is more volatile than the retail banking sector in the face of financial market turbulence, measured in this case as an unanticipated increase of stock market volatility. Wholesale banks are more volatile because they are more sensitive to market conditions due to their reliance on short-term financing. In addition, wholesale banks are not subject to the degree of regulation and monitoring that characterizes the retail sector, which may be another reason that the wholesale sector is more sensitive to market volatility. Furthermore, this contrast between the two sectors provides insights on why wholesale banks exhibit more procyclicality (positive co-movement with aggregate output) than their retail bank counterparts (as documented in, for example, Nuno and Thomas 2017 [44]): if the wholesale banking sector provides a channel through which financial market conditions affect the real economy while the retail sector does not, the wholesale sector naturally will tend to exhibit more positive co-movement with real aggregates, as long as financial shocks are an important driver of real volatility.

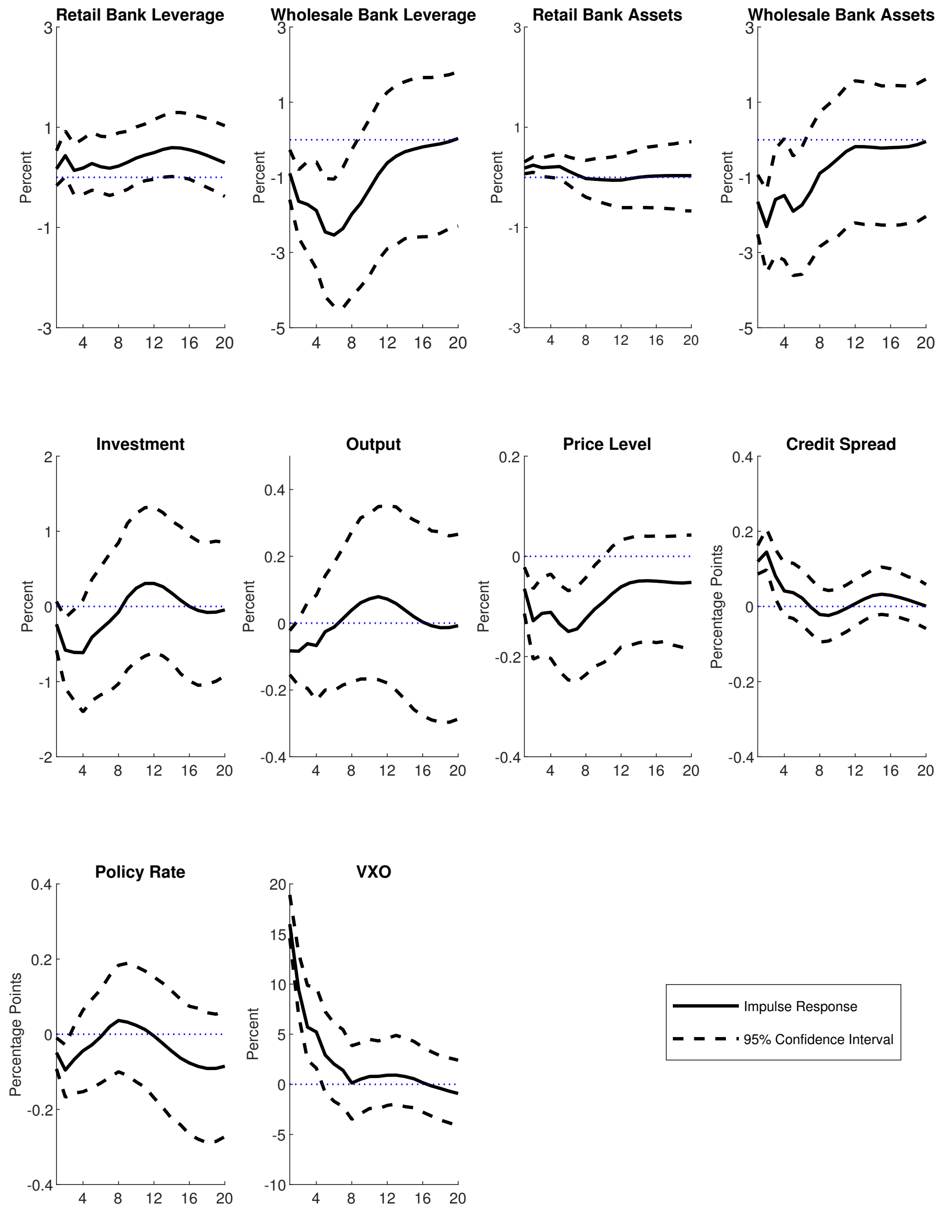

Figure 2.1: Response to Uncertainty Shock

To further explore the impact of uncertainty shocks, Figure 2.2 plots the share of forecast error variance at different horizons explained by the orthogonalized VXO shock for all variables in the benchmark VAR. 95% confidence intervals are computed with 2000 Monte Carlo simulations. Consistent with the impulse responses, the balance sheet of the wholesale banking sector is much more sensitive to fluctuations in uncertainty: about ten percent of the variation of wholesale leverage can be attributed to aggregate uncertainty shocks on impact, and this share rises to 20 percent at 8 quarters. Uncertainty shocks explain about 20 percent of the forecast error variance for wholesale assets on and shortly after impact. These shares are much smaller for the retail banking sector. Uncertainty shocks can also explain about five percent of variation in investment and output on impact.

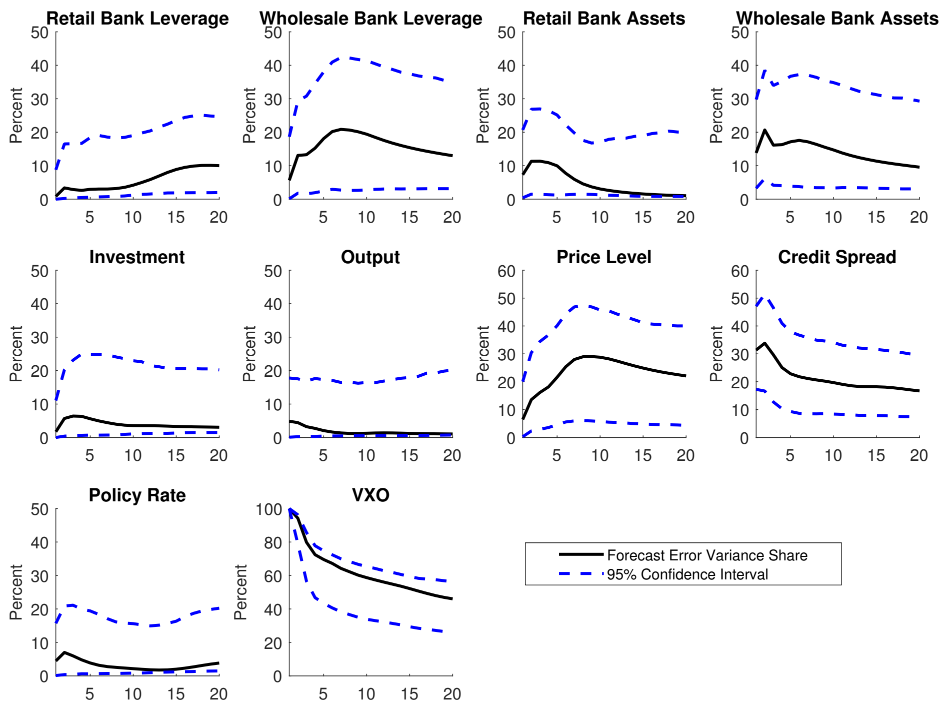

Figure 2.2: Forecast Error Variance Shares Explained by Uncertainty Shock

2.4 Shocks to Bank Leverage Ratios

To shed more light on the role of bank leverage as a possible channel through which aggregate uncertainty affects the economy, I also analyze the impacts of orthogonal shocks to bank leverage ratios in the benchmark VAR.

Figure 2.3 and Figure 2.4 show the impulse responses to a one standard-deviation negative shock to retail and wholesale bank leverage, respectively. Shocks to both retail and wholesale leverage ratios induce a decline in investment and output, although not significantly. In addition, co-movement between bank leverage and bank assets is much stronger for the wholesale sector than for the retail sector, as evident from the significant and prolonged drop of wholesale assets upon a negative shock to wholesale bank leverage that is absent for the retail sector.

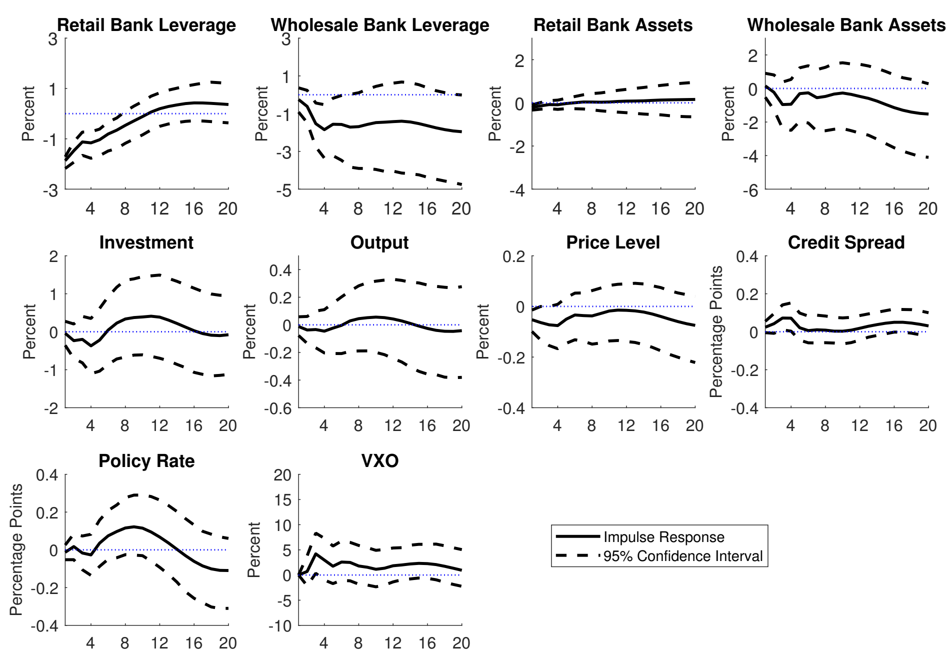

Figure 2.3: Impulse Responses: Shock to Retail Leverage

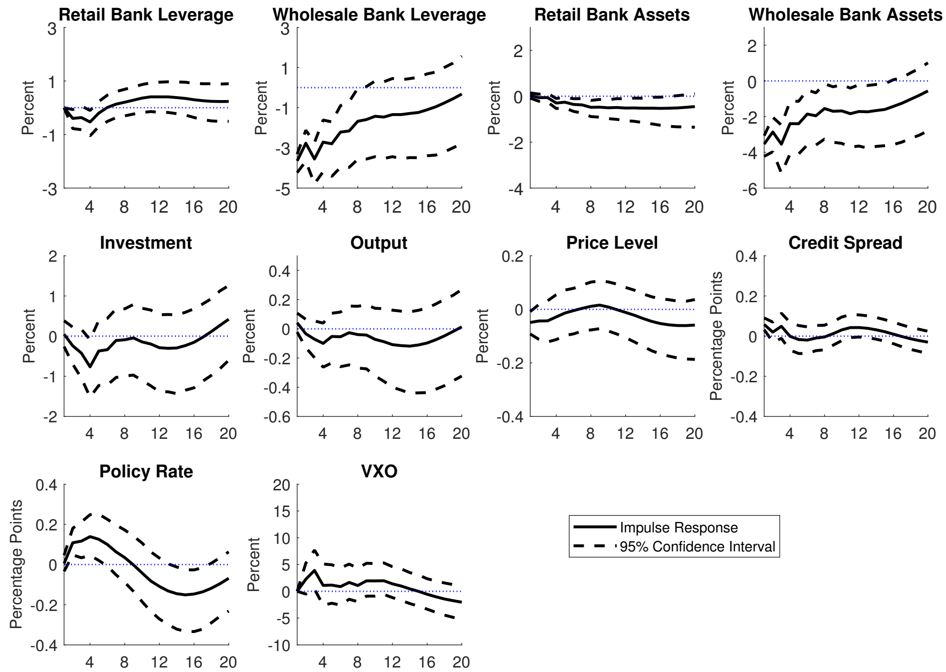

Figure 2.4: Impulse Responses: Shock to Wholesale Leverage

Figure 2.5 and 2.6 show the fraction of forecast error variance that is attributable to shocks to retail and wholesale bank leverage, respectively. Shocks to bank leverage do not explain much of the variation in investment and output, although the wholesale bank leverage shock appears more important than the retail bank leverage shock, explaining about five percent of investment at five quarters. Wholesale bank leverage shocks also explain more variation in monetary policy than retail bank leverage shocks. Between the two banking sectors, wholesale leverage shocks explain more variation of assets of both sectors than retail leverage. This reinforces evidence that while movements in bank leverage in both sectors contribute to fluctuations of the real economy, wholesale leverage may have a bigger impact for both the real aggregates and the financial sector itself.

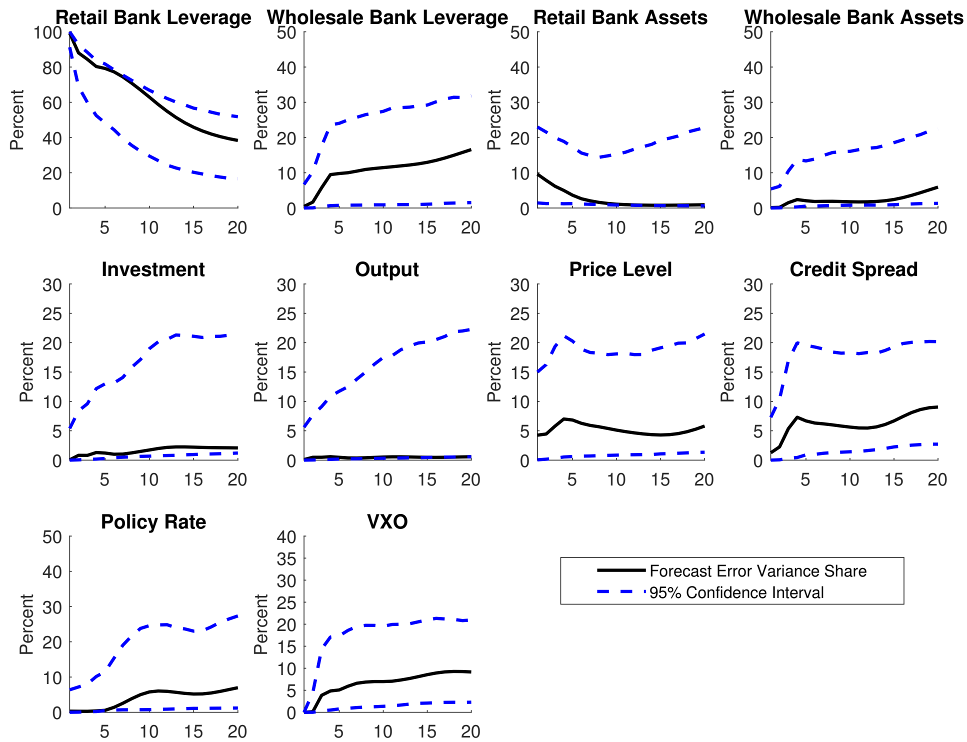

Figure 2.5: Forecast Error Variance Shares Explained by Shock to Retail Leverage

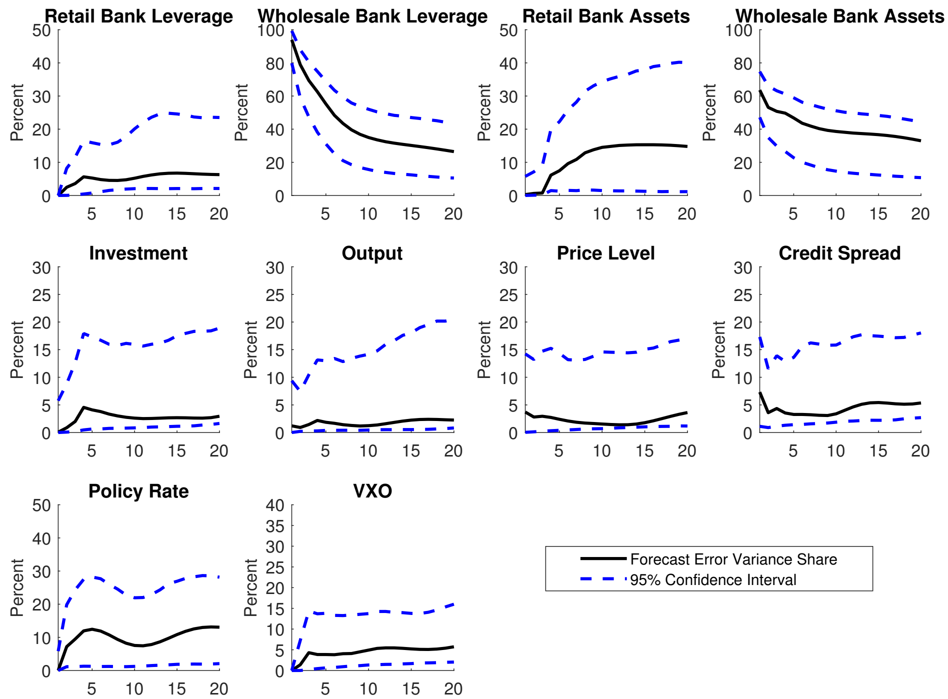

Figure 2.6: Forecast Error Variance Shares Explained by Shock to Wholesale Leverage

2.5 Robustness

It can be argued that instead of impacting real aggregates contemporaneously, shocks to uncertainty propagated via the financial sector may affect the real economy with a lag. Therefore, in an alternative VAR model, I order VXO and financial variables after investment and output. Figure 2.7 displays impulse responses to a positive shock to the VXO in a VAR with the following order: investment, output, the PCE deflator, VXO, retail bank leverage, wholesale bank leverage, retail bank assets, wholesale bank assets, the credit spread, and the Federal Funds Rate. As shown in Figure 2.7 , a positive shock to the VXO still induces significant drops in bank assets and subsequent declines in both investment, output, price level, and the policy rate.

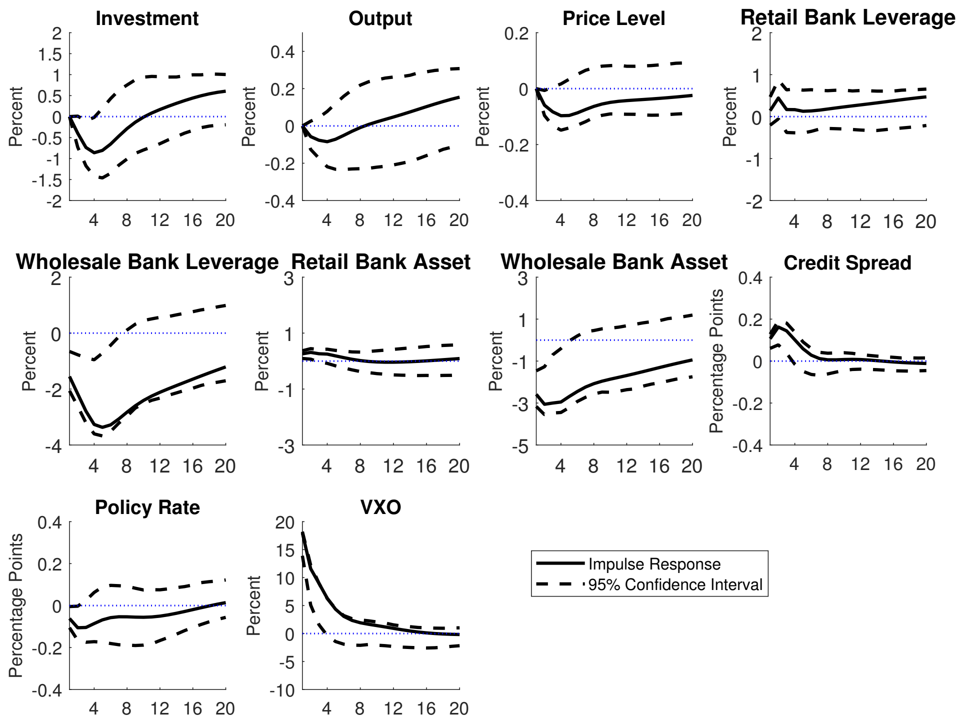

Figure 2.7: Responses to Uncertainty Shock: Alternative Ordering

2.6 Monetary Policy Shock

I also show in Figure 2.8 the responses to a monetary policy shock in the benchmark VAR model, where innovations in the Federal Funds Rate impact all other variables with a lag. A positive shock of one standard deviation to the policy rate increases it by 0.2 percentage points. This unexpected tightening of monetary policy raises market uncertainty and lowers bank assets significantly for both the wholesale and retail sectors. This suggests that aggregate uncertainty could be one channel through which monetary policy transmits to the financial sector. Wholesale bank leverage also drops and exhibits a similar trend with that of wholesale assets, while retail bank leverage does not decrease and shows very different patterns from retail bank assets. This could indicate that under monetary policy shocks, the wholesale bank balance sheet expands or contracts through changes in leverage constraints, whereas the size of the retail bank balance sheet is impacted independently of leverage ratios. In addition, both the leverage ratio and assets are more responsive for the wholesale sector than the retail sector.

Investment and output both decline significantly upon the policy shock, bottoming out at 1 and 0.3 percent below trend, respectively. The contractionary effect of a higher policy rate on the real economy thus could partly be due to contracting balance sheets of the financial sector, and particularly as a result of banks' reactions to increased levels of aggregate uncertainty following unexpected monetary policy changes.

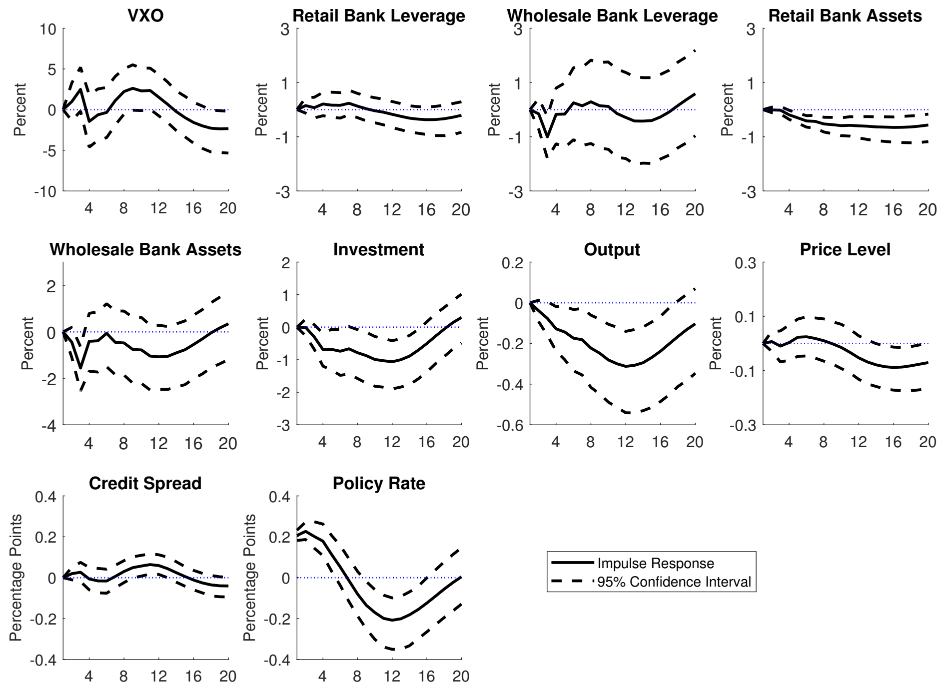

Figure 2.8: Response to Monetary Policy Shock

2.7 Conclusion

Together the VARs provide evidence that financial institutions are indeed a channel for aggregate uncertainty to impact the real economy. Bank leverage is important in how banks respond to market volatility as banks manage risk-taking via constraints on leverage ratios. Higher uncertainty levels directly tighten leverage ratios, which then reduce lending activities, subsequently dampening aggregate quantities and prices in the real economy. In addition, the impulse responses highlight the key role wholesale banks play in how the financial sector as a whole channels the effects of uncertainty shocks. While wholesale banks are very sensitive to aggregate market uncertainties, the retail banking sector is not nearly as responsive. When looking at the banking sector as a whole, the aggregate bank balance sheet may not show consistent reactions to sentiments in the financial market. This highlights the importance of studying wholesale and retail banks separately, especially in times when the wholesale sector is as large as the retail sector, for example since the 2000s.

Appendix A: Appendix for Chapter 1

A.1 Distribution of Firm Technology

As mentioned in Section 1.4, the downward risk of investing in the banks is defined as:

$\pi_t(x) \equiv \int^x (x-\omega) dF_t(\omega)$. Using integration by parts, it becomes: $\pi_t(x) = \int^x F_t(\omega) d\omega$. We then have:

$$\Delta\pi_t(x) = \chi\tilde{\pi}_t(x/\chi) - \pi_t(x) = \chi \int^{x/\chi} \tilde{F}_t(x/\chi) d\omega - \int^x F_t(\omega) d\omega.$$

From Assumption 2, $\tilde{F}_t(x) - F_t(\omega)$ is strictly increasing in x for $x \in (0, \omega_t^*)$. Furthermore, for any convex $\tilde{F}(x)$ [1], $\chi\tilde{F}_t(x/\chi) > F_t(x) \quad \forall x$ and $\forall \chi > 0$. We thus have:

$$\Delta\pi_t'(x) = \chi\tilde{F}_t(x/\chi) - F_t(\omega) > 0.$$

Therefore, $\Delta\pi(\bar{\omega};\sigma)$ increases in $\bar{\omega}$.

[1] The specific functional form for $\tilde{F}(x)$ is convex in this paper.

A.2 Solution to Banks' Problem

The problem for bank j of type i (i = W,R) (occurring at the lending stage) is:

$$V_t^i(N_t^{ij}) = \max_{A_t^{ij}, \bar{B}_t^{ij},, D_t^{ij}} E_t \Lambda_{t,t+1} \int_{\bar{\omega}_{t+1}^{ij}} [\theta^i V_{t+1}^i(N_{t+1}^{ij}) + (1-\theta^i)(N_{t+1}^{ij})] dF_t(\omega) \tag{A.1}$$

subject to the participation constraint (1.12), incentive constraint (1.13), the net worth equation

$$N_t^{ij} = A_{t-1}^{ij} R_t^i \omega_t^j - \bar{B}_{t-1}^{ij} - D_{t-1}^{ij} R_{t-1}^{Di} \tag{A.2}$$

the balance sheet constraint

$$A_t^{ij} = N_t^{ij} + B_t^{ij} + D_t^{ij} \tag{A.3}$$

and the definition of default threshold:

$$\bar{\omega}_t^{ij} \equiv \frac{\bar{B}_{t-1}^{ij} + D_{t-1}^{ij} R_{t-1}^{Di}}{A_{t-1}^{ij} R_t^i}. \tag{A.4}$$

In the earlier stage of the economy, equations (A.2) and (A.4) for $i = W$ become $N_t^{Wj} = A_{t-1}^{Wj} R_t^W \omega_t^j - (1+\mu)(\bar{B}_{t-1}^{Wj} + D_{t-1}^{Wj} R_{t-1}^{DW})$, and $\bar{\omega}_t^{Wj} \equiv \frac{(1+\mu)(\bar{B}_{t-1}^{Wj} + D_{t-1}^{Wj} R_{t-1}^{DW})}{A_{t-1}^{Wj} R_t^W}$, respectively.

Using λ_t^{ij} and ξ_t^{ij} as the multipliers for the participation and the incentive constraint, respectively, the objective of the bank then becomes:

$$V_t^i(N_t^{ij}) = \max_{A_t^{ij},\bar{b}_t^{ij},,\bar{d}_t^{ij}} \{E_t\Lambda_{t,t+1}\int_{\bar{\omega}_{t+1}^{ij}}[\theta^i V_{t+1}(N_{t+1}^{ij}) + (1-\theta^i)N_{t+1}^{ij}]dF_t(\omega)$$

$$+\lambda_t^{ij}[E_t\Lambda_{t,t+1}R_{t+1}^i A_t^{ij}(\int^{\bar{\omega}_{t+1}^{ij}}\omega dF_t(\omega) + \bar{\omega}_{t+1}^{ij}(1-F_t(\bar{\omega}_{t+1}^{ij}))) - (A_t^{ij} - N_t^{ij})]$$

$$+\xi_t^{ij}E_t\Lambda_{t,t+1}[\int_{\bar{\omega}_{t+1}^{ij}}[\theta^i V_{t+1}(N_{t+1}^{ij}) + (1-\theta^i)N_{t+1}^{ij}]dF_t(\omega)$$

$$-\int_{\bar{\omega}_{t+1}^{ij}/\chi^i}[\theta^i V_{t+1}(\tilde{N}_{t+1}^{ij}) + (1-\theta^i)\tilde{N}_{t+1}^{ij}]d\tilde{F}_t(\omega)]\}$$

where I define $\bar{b}_t^{ij} \equiv \frac{\bar{B}_t^{ij}}{A_t^{ij}}$, $\bar{d}_t^{ij} \equiv \frac{D_t^{ij}R_t^{Di}}{A_t^{ij}}$, which are the values of interbank and deposit debts normalized by the bank's assets. The choice variables hence become A_t^{ij} , $\bar{b}_t^{ij}$, and $\bar{d}_t^{ij}$. The default threshold can then be expressed as $\bar{\omega}_t^{ij} = \frac{\bar{B}_{t-1}^{ij}+D_{t-1}^{ij}R_{t-1}^{Di}}{A_{t-1}^{ij}R_t^i} = \frac{\bar{b}_{t-1}^{ij}+\bar{d}_{t-1}^{ij}}{R_t^i}$.

Note in the participation constraint, $E_t\Lambda_{t,t+1}R_t^D(B_t^{ij} + D_t^{ij})$ is replaced with $A_t^{ij} - N_t^{ij}$ using the first order condition of the household $E_t\Lambda_{t,t+1}R_t^D = 1$ as well as the balance sheet constraint of the wholesale bank. In the incentive constraint, as mentioned before, the bank's net worth becomes $\tilde{N}_{t+1}^{ij}$ when investing in substandard firms as a result of monitoring: $\tilde{N}_{t+1}^{ij} = \chi^i A_t^{ij}R_{t+1}^i\omega_{t+1}^j - \bar{B}_t^{ij} - D_t^{ij}R_t^{Di}$. This implies the default threshold is now higher: $\tilde{\bar{\omega}}_{t+1}^{ij} = \bar{\omega}_{t+1}^{ij}/\chi^i$ with $\chi^W < \chi^R = 1$.

The FOC with respect to A_t^{ij} is:

$$
\begin{aligned}
E_t\Lambda_{t,t+1}R_{t+1}^i \int_{\bar{\omega}_{t+1}^{ij}} [\theta^i V_{t+1}^{i'} + (1-\theta^i)](\omega - \bar{\omega}_{t+1}^{ij})dF_t(\omega) \\
+\lambda_t^{ij}\{E_t\Lambda_{t,t+1}R_{t+1}^i[\int^{\bar{\omega}_{t+1}^{ij}} \omega dF_t(\omega) + \bar{\omega}_{t+1}^{ij}(1 - F_t(\bar{\omega}_{t+1}^{ij}))] - 1\} \\
+\xi_t^{ij} E_t\Lambda_{t,t+1}R_{t+1}^i\{\int_{\bar{\omega}_{t+1}^{ij}} [\theta^i V_{t+1}^{i'} + (1-\theta^i)](\omega - \bar{\omega}_{t+1}^{ij})dF_t(\omega) \\
-\int_{\bar{\omega}_{t+1}^{ij}/\chi^i} [\theta^i V_{t+1}^{i'} + (1-\theta^i)](\chi^i\omega - \bar{\omega}_{t+1}^{ij})d\tilde{F}_t(\omega)\} = 0
\end{aligned} \tag{A.5}
$$

The FOC with respect to $\bar{b}_t^{ij}$ is:

$$
\begin{aligned}
E_t\Lambda_{t,t+1}\{-\frac{\theta^i V_{t+1}^i(0) f_t(\bar{\omega}_{t+1}^{ij})}{R_{t+1}^i} \\
-A_t^{ij}\int_{\bar{\omega}_{t+1}^{ij}} [\theta^i V_{t+1}^{i'} + (1-\theta^i)]dF_t(\omega)\} + \lambda_t^{ij} E_t\Lambda_{t,t+1}A_t^{ij}[1 - F_t(\bar{\omega}_{t+1}^{ij})] \\
+\xi_t^{ij} E_t\Lambda_{t,t+1}A_t^{ij}\{\frac{\theta^i V_{t+1}^i(0)\tilde{f}_t(\bar{\omega}_{t+1}^{ij}/\chi^i}{\chi^i A_t^{ij} R_{t+1}^i} - \frac{\theta^i V_{t+1}^i(0) f_t(\bar{\omega}_{t+1}^{ij})}{A_t^{ij} R_{t+1}^i} \\
+1/\chi^i \int_{\bar{\omega}_{t+1}^{ij}/\chi^i} [\theta^i V_{t+1}^{i'} + (1-\theta^i)]d\tilde{F}_t(\omega) - \int_{\bar{\omega}_{t+1}^{ij}} [\theta^i V_{t+1}^{i'} + (1-\theta^i)]dF_t(\omega)\} = 0
\end{aligned} \tag{A.6}
$$

The FOC with respect to $\bar{d}_t^{ij}$ arrives at the same equation as the FOC with respect to $\bar{b}_t^{ij}$ above.

The envelope condition is: $V_t^{i'}(N_t^{ij}) = \lambda_t^{ij}$.

We then guess that $V_t^i(N_t^{ij}) = \lambda_t^{ij} N_t^{ij}$ and that the multipliers are equalized across islands: $\lambda_t^{ij} = \lambda_t^i \forall j$; $\xi_t^{ij} = \xi_t^i \forall j$.

The FOCs for A_t^{ij} and $\bar{b}_t^{ij}$ then become (employing Kuhn-Tucker conditions):

$$
\begin{aligned}
E_t\Lambda_{t,t+1}R_{t+1}^i[\theta^i\lambda_{t+1}^i + (1-\theta^i)]\int_{\bar{\omega}_{t+1}^{ij}} (\omega - \bar{\omega}_{t+1}^{ij})dF_t(\omega) \\
+\lambda_t^i\{E_t\Lambda_{t,t+1}R_{t+1}^i[\int^{\bar{\omega}_{t+1}^{ij}} \omega dF_t(\omega) + \bar{\omega}_{t+1}^{ij}(1 - F_t(\bar{\omega}_{t+1}^{ij}))] - 1\} = 0
\end{aligned}
$$

and

$$\lambda_t^i E_t \Lambda_{t,t+1}[1 - F_t(\bar{\omega}_{t+1}^{ij})] - E_t \Lambda_{t,t+1}[\theta^i \lambda_{t+1}^i + (1-\theta^i)][1 - F_t(\bar{\omega}_{t+1}^{ij})]$$

$$+\xi_t^i E_t \Lambda_{t,t+1}[\theta^i \lambda_{t+1}^i + (1-\theta^i)][F_t(\bar{\omega}_{t+1}^{ij}) - 1/\chi^i \tilde{F}_t(\bar{\omega}_{t+1}^{ij}/\chi^i)] = 0$$

From these two equations, one can derive expressions for λ_t^i and ξ_t^i:

$$\lambda_t^i = \frac{E_t \Lambda_{t,t+1} R_{t+1}^i [\theta^i \lambda_{t+1}^i + (1-\theta^i)] \int_{\bar{\omega}_{t+1}^{ij}} (\omega - \bar{\omega}_{t+1}^{ij}) dF_t(\omega)}{1 - E_t \Lambda_{t,t+1} R_{t+1}^i [\int^{\bar{\omega}_{t+1}^{ij}} \omega dF_t(\omega) + \bar{\omega}_{t+1}^{ij}(1 - F_t(\bar{\omega}_{t+1}^{ij}))]} \tag{A.7}$$

and

$$\xi_t^i = \frac{\lambda_t^i E_t \Lambda_{t,t+1}[1 - F_t(\bar{\omega}_{t+1}^{ij}))] - E_t \Lambda_{t,t+1}[\theta^i \lambda_{t+1}^i + (1-\theta^i)][1 - F_t(\bar{\omega}_{t+1}^{ij}))]}{E_t \Lambda_{t,t+1}[\theta^i \lambda_{t+1}^i + (1-\theta^i)][1/\chi^i \tilde{F}_t(\bar{\omega}_{t+1}^{ij}/\chi^i) - F_t(\bar{\omega}_{t+1}^{ij})]} \tag{A.8}$$

In steady state these become:

$$\lambda^i = \frac{\beta R^i (1-\theta^i) \int_{\bar{\omega}^{ij}} (\omega - \bar{\omega}^{ij}) dF_t(\omega)}{1 - \beta R^i + (1-\theta^i) \beta R^i \int_{\bar{\omega}^{ij}} (\omega - \bar{\omega}^{ij}) dF_t(\omega)}$$

and

$$\xi^i = \frac{(\lambda^i - \theta^i \lambda^i + \theta^i - 1)(1 - F_t(\bar{\omega}^{ij}))}{(\theta^i \lambda^i + 1 - \theta^i)[1/\chi^i \tilde{F}_t(\bar{\omega}^{ij}/\chi^i) - F_t(\bar{\omega}^{ij})]} = \frac{(\lambda^i - 1)(1-\theta^i)(1 - F_t(\bar{\omega}^{ij}))}{(\theta^i \lambda^i + 1 - \theta^i)[1/\chi^i \tilde{F}_t(\bar{\omega}^{ij}/\chi^i) - F_t(\bar{\omega}^{ij})]}$$

Thus if we choose parameter values that satisfy :

$0 < \beta R^A - 1 < (1-\theta^W) \beta R^i \int_{\bar{\omega}^{ij}} (\omega - \bar{\omega}^{ij}) dF_t(\omega)$, then in steady state $\lambda^i > 1 > 0$, i.e., the participation constraint binds in steady state. In addition, if $\bar{\omega}^{ij} \geq \omega*$ the incentive constraint will be violated in steady state, thus we have

$\bar{\omega}^{ij} < \omega*$. With Assumption 2 and $\lambda^i > 1$, we then have $\xi^i > 0$, i.e. the incentive constraint also binds in steady state.

If shocks are small, around the steady state we then have $\lambda_t^i > 1(>0), \xi_t^i > 0$. With the incentive constraint binding with equality, we have:

$$E_t\Lambda_{t,t+1}R_{t+1}^i[\theta^i\lambda_{t+1}+(1-\theta^i)][\int_{\bar{\omega}_{t+1}^{ij}}(\omega-\bar{\omega}_{t+1}^{ij})dF_t(\omega)-\int_{\bar{\omega}_{t+1}^{ij}/\chi^i}(\chi^i\omega-\bar{\omega}_{t+1}^{ij})d\tilde{F}_t(\omega)] = 0.$$

From the above equation it can be seen that $\bar{\omega}_t^{ij} = \bar{\omega}_t^i \forall j$, which implies $\bar{b}_t^{ij} = \bar{b}_t^i \forall j$. Plugging these results back into the equations for λ_t^i, ξ_t^i we then have $\lambda_t^{ij} = \lambda_t^i, \xi_t^{ij} = \xi_t^i \forall j$, which verifies our guess that the two multipliers are equal across islands.

With participation constraint holding with equality we have: $E_t\Lambda_{t,t+1}R_{t+1}^iA_t^{ij}\{\int^{\bar{\omega}_{t+1}^i}\omega dF_t(\omega) + \bar{\omega}_{t+1}^i[1-F_t(\bar{\omega}_{t+1}^i)]\} = A_t^{ij} - N_t^{ij}$, we can solve for the leverage ratio:

$$\phi_t^{ij} \equiv A_t^{ij}/N_t^{ij} = \frac{1}{1 - E_t\Lambda_{t,t+1}R_{t+1}^i\{\int^{\bar{\omega}_{t+1}^i}\omega dF_t(\omega) + \bar{\omega}_{t+1}^i[1-F_t(\bar{\omega}_{t+1}^i)]\}} = \phi_t^i \quad \forall j$$

Using the guess that $V_t^i(N_t^{ij}) = \lambda_t^i N_t^{ij}$ for period t+1 we have:

$$V_t^i(N_t^{ij}) = E_t\Lambda_{t,t+1}\int_{\bar{\omega}_{t+1}^i}[\theta^i V_{t+1}^i(N_{t+1}^{ij}) + (1-\theta^i)(N_{t+1}^{ij})]dF_t(\omega)$$

$$= A_t^{ij}E_t\Lambda_{t,t+1}R_{t+1}^i[\theta^i\lambda_{t+1}^i + 1 - \theta^i]\int_{\bar{\omega}_{t+1}^i}(\omega - \bar{\omega}_{t+1}^i)dF_t(\omega).$$

Equating the left hand side with $V_t^i(N_t^{ij}) = \lambda_t^i N_t^{ij}$ and using the equation for

ϕ_t^{ij} from above, we can then solve for λ_t^i:

$$\lambda_t^i = \frac{E_t \Lambda_{t,t+1} R_{t+1}^i [\theta^i \lambda_{t+1}^i + (1-\theta^i)] \int_{\bar{\omega}_{t+1}^i} (\omega - \bar{\omega}_{t+1}^i) dF_t(\omega)}{1 - E_t \Lambda_{t,t+1} R_{t+1}^i [\int^{\bar{\omega}_{t+1}^i} \omega dF_t(\omega) + \bar{\omega}_{t+1}^i (1 - F_t(\bar{\omega}_{t+1}^i))]}$$

which coincides with the equation solved for λ_t from the FOC for A_t^{ij} (equation (A.7)) and thus verifies the guess.

The results of the problem of bank j of type i can thus be summarized as follows:

The bank's net worth at beginning of period t satisfies:

$$N_t^{ij} = A_{t-1}^{ij} R_t^i \omega^j - \bar{B}_{t-1}^{ij} - D_{t-1}^{ij} R_{t-1}^{Di} \tag{A.9}$$

The balance sheet constraint is:

$$A_t^{ij} = N_t^{ij} + B_t^{ij} + D_t^{ij}. \tag{A.10}$$

The first order conditions are (A.5) and (A.6). The participation constraint holds with equality:

$$\phi_t^i \equiv \frac{A_t^{ij}}{N_t^{ij}} = \frac{1}{1 - E_t \Lambda_{t,t+1} R_{t+1}^i [\int^{\bar{\omega}_{t+1}^i} \omega dF_t(\omega) + \bar{\omega}_{t+1}^i (1 - F_t(\bar{\omega}_{t+1}^i))]} \tag{A.11}$$

And the incentive constraint holds with equality:

$$E_t\Lambda_{t,t+1}R^i_{t+1}[\theta^i\lambda^i_{t+1}+1-\theta^i][\int_{\bar{\omega}^i_{t+1}}(\omega-\bar{\omega}^i_{t+1})dF_t(\omega)-\int_{\bar{\omega}^i_{t+1}}(\omega-\bar{\omega}^i_{t+1})d\tilde{F}_t(\omega)]=0\Rightarrow$$

$$\begin{aligned} E(\omega)-\chi^i E(\tilde{\omega}) &= E_t\{\frac{\Lambda_{t,t+1}R^i_{t+1}[\theta^i\lambda^i_{t+1}+1-\theta^i]}{E_t\Lambda_{t,t+1}R^i_{t+1}[\theta^i\lambda^i_{t+1}+1-\theta^i]} \\ (\chi^i\int^{\bar{\omega}^i_{t+1}/\chi^i}&(\bar{\omega}^i_{t+1}/\chi^i-\omega)d\tilde{F}_t(\omega)-\int^{\bar{\omega}^i_{t+1}}(\bar{\omega}^i_{t+1}-\omega)dF_t(\omega))\} \end{aligned} \tag{A.12}$$

where we have used $\int_{\bar{\omega}^i_{t+1}}(\omega-\bar{\omega}^i_{t+1})dF_t(\omega)=E(\omega)+\int^{\bar{\omega}^i_{t+1}}(\bar{\omega}^i_{t+1}-\omega)dF_t(\omega)-\bar{\omega}^i_{t+1}$.

A.3 Model Solution Summary

The model equilibrium can be summarized by the following 30-equation system for the 30 endogenous variables

$Y_t, C_t, I_t, L_t, K_t, R^D_t, R^i_t, \bar{\omega}^i_t, \bar{b}^i_t, \bar{d}^i_t, \lambda^i_t, N^i_t, A^i_t, \phi^i_t, B^i_t, D^i_t, \bar{B}^i_t, \phi_t, N_t$, for i = W,R. :

$$E_t\frac{\beta u'(C_{t+1})}{u'(C_t)}R^D_t=1 \tag{A.13}$$

$$\frac{\nu'(L_t)}{u'(C_t)}=(1-\alpha)\frac{Y_t}{L_t} \tag{A.14}$$

$$Y_t=C_t+I_t+\sum_i\gamma^i A^i_{t-1}+\mu(\bar{B}^W_{t-1}+D^W_{t-1}R^D_{t-1}) \tag{A.15}$$

$$Y_t = Z_t K_t^{\alpha} L_t^{1-\alpha} + \sum_i (1-\theta^i)[1-F_{t-1}(\bar{\omega}_t^i)]W^i \tag{A.16}$$

$$K_{t+1} = \sum_i A_t^i \tag{A.17}$$

$$K_{t+1} = I_t + (1-\delta)K_t \tag{A.18}$$

$$R_t^i = (1-\delta) + \alpha Y_t / K_t - \gamma^i \tag{A.19}$$

$$\bar{\omega}_t^i = (\bar{b}_{t-1}^i + \bar{d}_{t-1}^i)/R_t^i \tag{A.20}$$

$$\bar{b}_t^i = \bar{B}_t^i / A_t^i; \quad \bar{d}_t^i = D_t^i R_t^{Di} / A_t^i \tag{A.21}$$

$$\lambda_t^i = \frac{E_t \frac{\beta u'(C_{t+1})}{u'(C_t)} R_{t+1}^i [\theta^i \lambda_{t+1}^i + (1-\theta^i)] \int_{\bar{\omega}_{t+1}^i} (\omega - \bar{\omega}_{t+1}^i) dF_t(\omega)}{1 - E_t \frac{\beta u'(C_{t+1})}{u'(C_t)} R_{t+1}^i [\int^{\bar{\omega}_{t+1}^i} \omega dF_t(\omega) + \bar{\omega}_{t+1}^i (1 - F_t(\bar{\omega}_{t+1}^i))]} \tag{A.22}$$

$$E(\omega) - \chi^i E(\tilde{\omega}) = E_t \{ \chi^i \int^{\bar{\omega}_{t+1}^i / \chi^i} (\bar{\omega}_{t+1}^i / \chi^i - \omega) d\tilde{F}_t(\omega) - \int^{\bar{\omega}_{t+1}^i} (\bar{\omega}_{t+1}^i - \omega) dF_t(\omega) \} \tag{A.23}$$

$$E_t\Lambda_{t,t+1}R^i_{t+1}A^{ij}_t\{\int^{\bar{\omega}^i_{t+1}}\omega dF_t(\omega)+\bar{\omega}^i_{t+1}[1-F_t(\bar{\omega}^i_{t+1})]\}=A^i_t-N^i_t \tag{A.24}$$

$$A^i_t=N^i_t+B^i_t+D^i_t \tag{A.25}$$

$$\sum_i B^i_t=0 \tag{A.26}$$

$$D^W_t=0 \tag{A.27}$$

$$A^i_t=N^i_t\phi^i_t \tag{A.28}$$

$$N^i_t=\theta^iR^i_tA^i_{t-1}\int_{\bar{\omega}^i_t}(\omega-\bar{\omega}^i_t)dF_{t-1}(\omega)+(1-\theta^i)[1-F_{t-1}(\bar{\omega}^i_t)]W^i \tag{A.29}$$

$$\phi_t=(\sum_i A^i_t)/(\sum_i N^i_t) \tag{A.30}$$

$$N_t=\sum_i N^i_t \tag{A.31}$$

The exogenous processes of the system include an AR(1) process (in logs) for aggregate TFP Z_t and an AR(1) process for the standard of island-specific shocks deviation σ_t. Because the volatility of island-specific returns on capital affects the expected returns on bank assets and thus affects the participation and incentive constraints imposed on bank lending, it eventually affects bank leverage and bank loans.

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